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SURVEY AND ASSESSMENT OF THE MINE FIRE PREVENTION AND CONTROL PRACTICES IN COAL MINES

For

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1. INTRODUCTION

Most of the major disasters which have occurred in coal mines have been associated with fires and explosions. During the late-nineteenth and early twentieth centuries the major coal mining countries experienced many such disasters, which would affect extensive areas of mines and result in numerous fatalities. Considerable progress has been made since that time in reducing the frequency of incidents and limiting their spread. However, fires and explosions remain among the greatest potential hazards in mining. The introduction of advanced mining technologies has given rise to new sources of ignition and this has been concurrent with the requirement to mine seams with more difficult and hazardous mining and geologic conditions.

Although a definitive distinction between a fire and an explosion is possible, for all practical mining purposes an explosion is accompanied by flame which, dependent on prevailing circumstances, may be quickly extinguished or may persist as an open or hanging flame giving rise to fire. Fires originating in this manner may remain surficial and be brought under control using conventional fire fighting techniques, alternatively they may gain a deep-seated hold.

There are two basic types of fire, namely, gob fires and open fires. The ability of coal to self-ignite is well known. In the case of spontaneous combustion, the fire or heating zone generally extends towards the source of oxygen. However, dependent on location the gob fire may, if uncontrolled, break out into an open fire in either intake or return roadways. The combination of deep-seated gob fire and open fire presents a most serious situation. Open fires vary from small local occurrences to severe situations in which the main combustion zone may be restricted due to fuel availability or may rapidly extend along a roadway(s). For example, a fire involving a

limited quantity of spilled oil may be small and quickly brought under control. A severe fire involving timber supports and coal may spread rapidly. When the fuel is methane a fire only occurs after the ignition, if the gas continues to burn. The size of the fire will depend on the amount of methane available and the extent to which other materials are ignited. Methane is an exceptionally hazardous combustible fuel as, once ignited, it may continue to burn in inaccessible locations in the strata or gob with the continual risk that it may contact an explosive mixture.

The essential ingredients for a fire to be initiated are a source of ignition, combustible material and a supply of oxygen. As "prevention is better than cure" the first approach to the solution of the mine fire problem involves maximum use of available preventive measures to eliminate igniting sources, and to eliminate or render non-flammable all combustible materials as far as is practicable. As it will never be possible to completely eliminate the occurrence of mine fires, the availability of suitably trained personnel, properly and fully equipped, will enable rapid control to be achieved and prevent major fires developing from small beginnings. In the event that a severe fire does develop, decisive action needs to be initiated based on a consideration of all related details. The factors to be considered are the location, type and intensity of the fire; the extent of life at risk; the combustible materials involved and available; and the system, quantity and direction of ventilation. The major objective is to secure the safety of the men and subsequently to extingush the fire and bring the situation under control with the minimum of risk to the fire-fighters.

2. GOB FIRES

2.1 SOURCES OF IGNITION

Gob fires are deep-seated incidents which result from spontaneous combustion. This process, which consists of the self heating of coal or other materials, has been a problem for as long as the mineral has been mined.

The phenomenon is one which results in the production of heat due to the chemical reaction between oxygen and some oxidizable material. Spontaneous combustion of coal is due to oxidation of the carbon substance. Different coal types absorb oxygen in varying degrees and those most susceptible to this process are said to be "liable to spontaneous combustion."

Even at room temperature coal reacts with oxygen and the gaseous oxides of carbon are produced. This oxidation process, in practical mining terms, becomes significant when local temperature increases occur, as this temperature rise increases the rate of oxidation. The process is encouraged when the fuel is a good thermal insulator so preventing escape of heat generated in the reaction. The temperature at which this process commences, and is self-sustaining, is known as the spontaneous ignition temperature and it is the lowest temperature at which a substance will ignite spontaneously and burn without the introduction of a flame or source of external ignition. This temperature usually lies within the range 70°C-150°C, dependent upon coal type.

2.2 COMBUSTIBLE MATERIALS

The results of extensive laboratory tests over the years into the absorption of oxygen by coal has resulted in the general conclusion that "the lower the rank the more oxidizable is the coal, particularly at lower

temperatures" (Chamberlain, 1970). This general statement must, however, be qualified as a significant factor in the heating process is the physical condition of the coal. In a finely divided state, coal presents large surface areas and is therefore, more liable to oxidize. Thus, any mining situation and associated process, which results in the coal being in this physical condition, is potentially hazardous and must be considered suspect.

High moisture coals are, in general, more prone to spontaneous combustion. Absorption of water by coal accelerates, and desorption retards, the process. The heat produced during absorption of water vapour causes acceleration of the combustion process.

Sulphur, present in coal seams in the form of pyrite, may also be a catalyst in the oxidation process. Its presence can cause an initial temperature rise and, by swelling, cause breakage of the coal resulting in an increased surface area being exposed to oxygen (Staff, Mines Department, 1921). Five cases of spontaneous heatings in high rank coals in South Wales have occurred and in each case the sulphur content of the seam was of the order of 6 percent (Chamberlain, 1970).

Thus, organic materials based on carbon, such as coal, are likely to develop spontaneous combustion. This most readily occurs when the following conditions exist:

- coal is present in a finely divided state
- a supply of oxygen is in contact with this coal

The air supply must be limited in quantity and velocity or heat from the oxidation process will be dissipated and the ignition temperature will not be reached. Conversely, the amount of air must be sufficient to supply the oxygen for the reaction to continue or, yet again, the spontaneous heating will not develop.

Although the above criteria appear stringent, it is important to remember that the condition most liable to lead to a spontaneous heating is when air leakage is small. Mining situations frequently create such circumstances.

2.3 PRODUCTS OF COMBUSTION

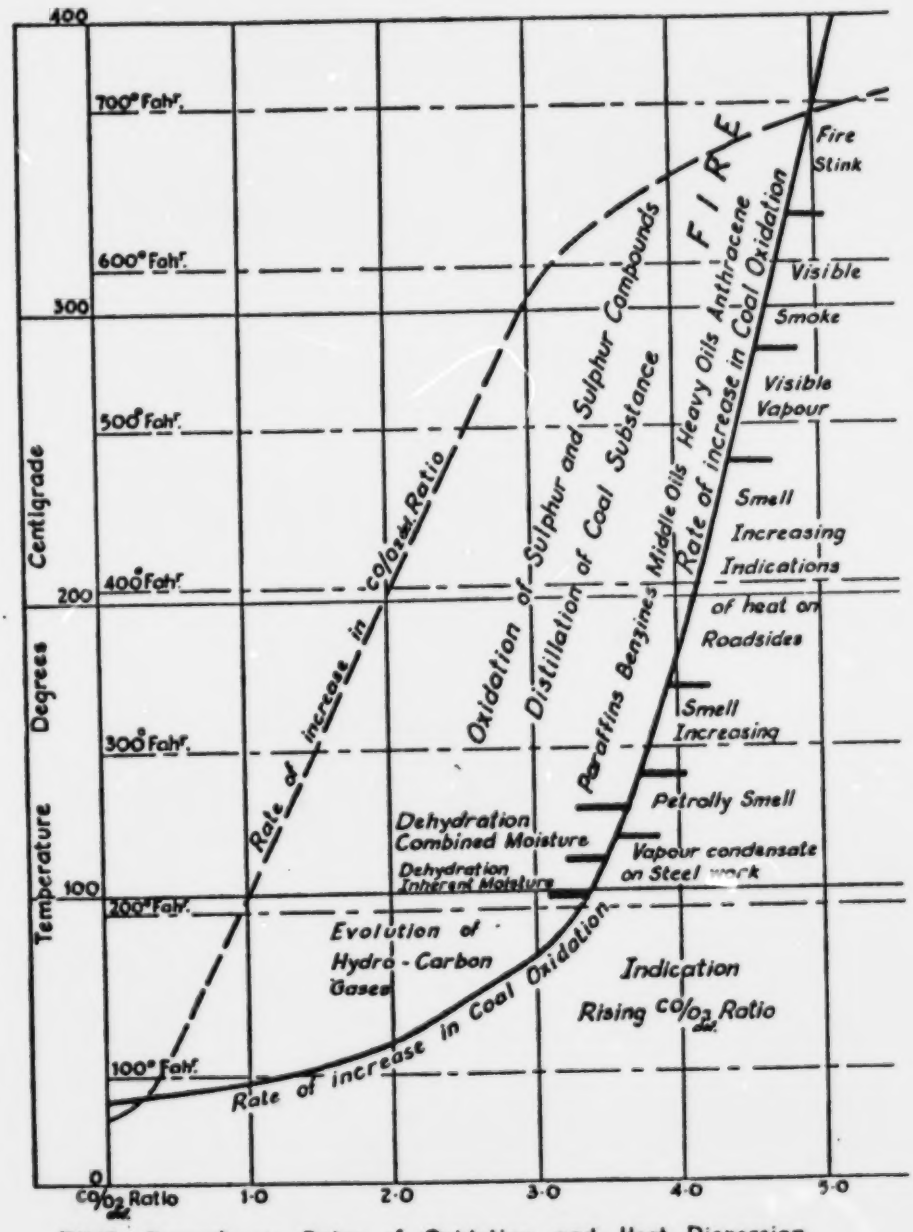
The development of spontaneous combustion is depicted in Figure 1. The products of combustion are, essentially, carbon monoxide and gaseous hydrocarbons together with complex distillates. The diagram indicates that carbon monoxide is the earliest indicator of an incipient spontaneous combustion. The rate of evolution of carbon monoxide begins to increase rapidly at about 50°C, whereas hydrogen, ethylene and propylene do not show a similar rapid rate of increase until temperatures of over 100°C are reached. These latter gases may be used to trace the progress of a heating, but carbon monoxide is the most sensitive indicator (Chamberlain, 1970).

2.4 LOCATION OF GOB FIRES

The conditions for the development of a spontaneous heating have been stated above. In the mining environment these circumstances are inherent in a mining strategy which presently incorporates mechanization, concentration of production, rapid rates of extraction, multi-seam and multi-slice extraction, and outcrop mining (Feng, 1973). In highly mechanized mines, a considerable amount of coal fines is produced during mining operations which, if accumulated in the worked out areas, can be a source of danger.

Connecting galleries are made in multiple-entry systems between parallel development roadways. The majority of these connecting roadways are not used during the extraction process and crushed coal can gather in these zones.

With the room and pillar method of mining, abutment pillars are left for support of the worked out area during depillaring operations. Crushing of these abutment pillars results in coal fines.



TIME. Depends on Rates of Oxidation and Heat Dispersion.

FIGURE 1

DEVELOPMENT OF SPONTANEOUS COMBUSTION

SOURCE: EVANS, 1970.

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Working of thick seams is always accompanied by exploitation losses as full extraction is often neither feasible nor economical due to the constraints imposed by the range of the equipment being used. Roof and/or floor coal may be left, when the adjoining strata are weak, to provide better working conditions at the working face. Also poorer quality sections of the seam may be left in-situ. Caving of the coal roof or heaving of the floor results in coal fines and creates leakage airflow paths.

The close proximity of coal seams often results in the access of ventilating air into old workings. Similarly, a seam of coal in the immediate roof of any working can collapse in the caved waste and its resultant degradation causes the formation of coal fines. Alternatively such seams may spontaneously heat in-situ.

Mining of coal under shallow cover or near the outcrop is common. If the roof strata cave to the surface, an air leakage path is established into worked out areas.

The presence of faults in coal seams often aids in the development of spontaneous heatings. Coal in the immediate vicinity of a fault is usually in a finely-divided state. Planes of weakness usually develop in the fault zone and provide leakage paths for air.

Strata temperature increases with depth due to geothermal gradient. Therefore, rate of oxidation will increase with depth making the deeper seams more vulnerable to spontaneous combustion.

High ventilation pressure differentials result in air leakage and are, therefore, a major contributory factor to spontaneous combustion. Locations where there is a pressure difference must be considered as a likely source of a heating. These include ventilation doors, regulators, air crossings, and local constrictions in mine airways. Regulators and doors,

unless they are well sealed, will allow air leakages through fractured coal around them. Ventilation pressure differences across strata breaks in the vicinity of air crossings are often high and the resultant air leakage can cause a heating.

2.5 HAZARDS ASSOCIATED WITH GOB FIRES

A spontaneous heating is an insidious hazard. As depicted in Figure 1 it is important to appreciate that a spontaneous combustion, if not controlled, can ultimately break out into an open fire. In the case of spontaneous combustion, the heating zone moves back towards its intake air supply and the open fire will break out at the intake end of the zone (Thorp, 1974). Concurrently, a spontaneous heating produces toxic gases and asphyxiating fumes. These travel downwind, carried by the ventilating current, and can endanger men remote from the location of the heating.

The uncontrolled development of spontaneous heating can result in the risk of dust or gas explosions which may cause loss of life and tremendous physical damage. In extreme cases this can result in the loss of part, or the whole, of the mine.

2.6 CIRCUMSTANCES FAVOURING GOB FIRES

Circumstances favouring the development of a spontaneous heating are the presence of coal fines in association with a critical oxygen supply from a secondary air circuit. Table 1 summarizes the critical factors contributing to spontaneous combustion (Feng, 1973).

There is no single obvious criterion by which it is possible to assess if the working of a coal seam will result in liability to spontaneous combustion. The geological conditions and the coal properties need to be considered for each seam to be worked and a decision then made on the intended mining practice, in each case, according to the specific conditions.

TABLE 1

CRITICAL FACTORS CONTRIBUTING TO SPONTANEOUS COMBUSTION

Intrinsic Factors Which Cannot Be Controlled		Extrinsic Factors Which Can Be Controlled
Coal Properties	Geological Features	Mining Practice
1. Low rank	1. Presence of faults in coal seams	1. High losses of coal in worked out area
2. High moisture	2. Weak and disturbed strata condition	2. Excessive fissuration due to strata movement (stress relief)
3. High pyrite	3. Thick seams with bands of inferior coal	3. Caving to surface under shallow overburden or near outcrop
4. High friability	4. Seams under shallow overburden	4. Mining of thick seam by caving - partial extraction of seams
	5. Multi-seams in close proximity	5. Ventilation anomalies - imbalances, constrictions, large pressure differential, etc.

3. GOB FIRE PREVENTION, DETECTION AND CONTROL

3.1 MINE PLANNING AND PREVENTION OF GOB FIRES

Conditions encouraging a gob fire are coal surfaces exposed to a limited oxygen supply. In practice these conditions can be minimized by a combination of good mining layout and ventilation techniques, i.e., by good mine planning. Some of the precautions to be taken are shown in Figure 2.

Mining layouts should be as simple as practicable and individual working places should be capable of being quickly isolated and sealed off. For each planned working section, sites for preparatory seals should be selected. Mine planning should incorporate the provision of a centrally-placed emergency station housing appropriate equipment

The layout relative to other extraction areas, both existing and proposed, and in other seams, must be such that interaction does not result in them being adversely affected. Total extraction usually results in better destressing patterns. Remnant pillars result in high stress zones which cause mining difficulties in the future.

Retreat mining has obvious practical advantages in that the gob area is inbye of the mining activity. This applies to both longwall and room and pillar operations as depillaring is a retreat mining operation. The important factor is to establish the operation to ensure a regular and definitive caving or closure pattern and, wherever possible, avoid leaving small coal pillars in the waste area.

Coal pillars, for support purposes, are usually an integral part of any mining design. In planning against spontaneous combustion the size of these pillars must be designed to ensure they are dimensionally stable and capable of resisting excessive crush.

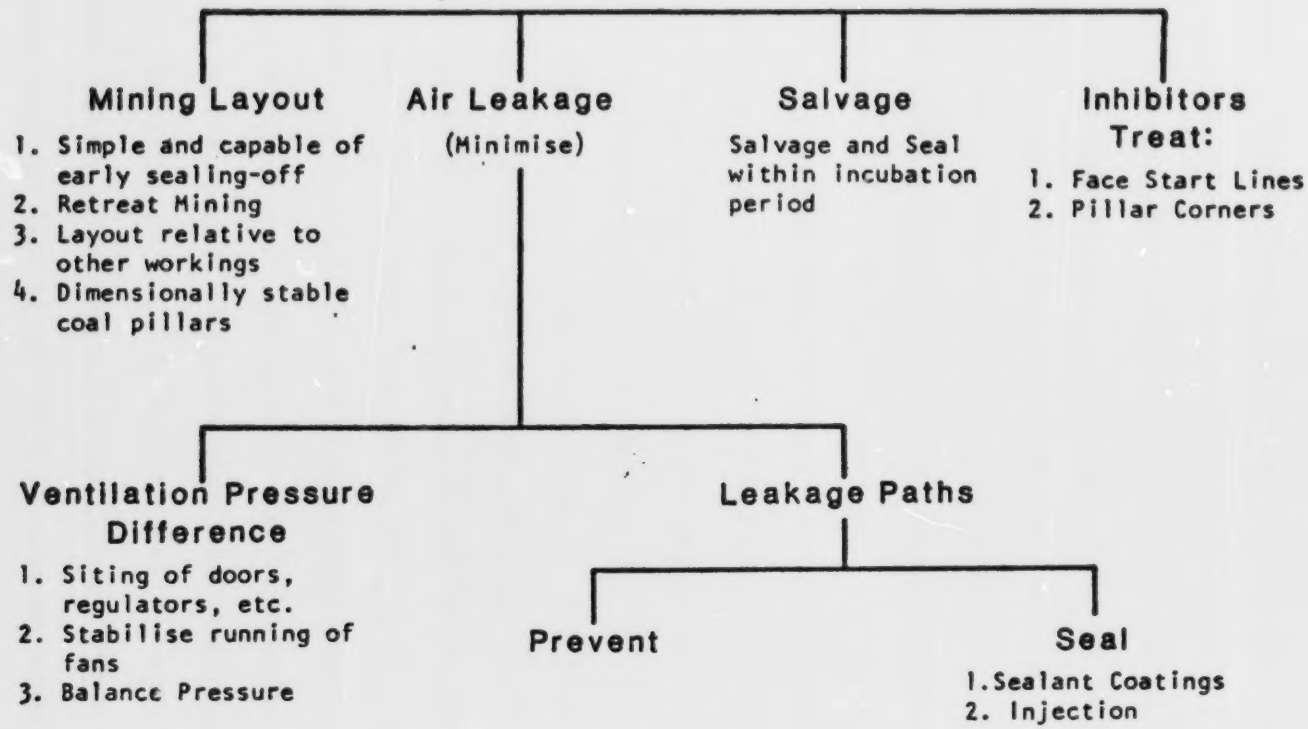

FIGURE 2

PRECAUTIONS AGAINST
SPONTANEOUS COMBUSTION

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The generally-held opinion is that rapid rates of extraction are better than low rates of working face advance in preventing spontaneous combustion in the gob. Mine planning must be such that this objective is achieved. The gob area immediately behind working faces is subject to rapidly changing strata conditions relative to the more distant areas where consolidation has taken place. As a result, the quantity of air leakage through a given location in the gob can normally be expected to reduce as the working face moves away. Assuming that oxidizable material is uniformly present, the period of high risk of spontaneous combustion is reduced as the rate of face advance increases. This assumes that the degree of consolidation at specific distances from the face remains constant while the advance rate varies.

Given the premise that, in appropriate environmental circumstances, all coals must be considered suspect in relation to tendency to spontaneous combustion, control of air leakage is the key to the prevention of gob fires.

The ventilation pressure difference across a section of workings is one major factor in controlling spontaneous heatings. Pressure absorption rates must be even and pressure differences must be maintained at a constant value. Localized, uncontrolled pressure differences must be avoided. Doors, regulators and seals need to be well constructed and properly sited. Unnecessary stopping and starting of main ventilation fans should be avoided. Once a production area has finished and been sealed off, the ventilation pressure on the face of the seals should be balanced, as far as is practicable. The importance of this factor cannot be overstressed as most worked out areas become interconnected after cavings, and a fire developing in an abandoned area can lead to gob fires in adjacent areas, with their attendant hazards.

Air leakage paths should be minimised by providing adequate support in the form of sufficiently sized coal pillars, or good roadside packs, dependent upon the method of mining being practised. Pillar corners may need stabilizing and strata breaks should be sealed with a noncombustible sealant coating. A recommended practice is to calculate the ventilation efficiency for any section of workings and, should this fall below a predetermined level, investigation into the leakages occurring should be undertaken.

The period of highest susceptibility to spontaneous heating, in the life of a production unit, occurs as production ceases. Mine planning should incorporate the salvaging of equipment and the sealing of the district in the shortest possible time. Whenever practical, it is good practice to minimise the amount of coal left in the gob during the period immediately preceding the halting of production.

When a production unit stops it would appear logical, having regard to the spontaneous combustion hazard, to reduce considerably the circulating air quantity. This reduces the ventilating pressure difference across the zone and the tendency for leakage airflow. However, when such an action is contemplated, account must be taken of methane levels in the ventilating airstream. The reduced air quantity must be sufficient to dilute noxious and inflammable gases to safe percentages and ventilation pressure must be maintained at a sufficient level to prevent dangerous emissions of gases from the gob.

Any measure which prolongs the spontaneous heating incubation period after a unit ceases production, makes more time available for safe withdrawal from the unit.

3.2 DETECTION

The traditional classic physical symptoms of a heating are smell, smoke, sweating and haze. Their occurrence in relation to the development of spontaneous combustion are shown on Figure 1.

The term "gob stink" is well known. Many men with wide experience of gob fires place great emphasis on their ability to detect spontaneous combustion by their sense of smell. This method, though still used, has the major drawback of being purely subjective and nonquantitative.

Traditionally, heatings have been detected in their early stages by methods based on changes in temperature or changes in air composition. Thermometers and thermocouples are used to monitor temperature variations in vulnerable zones and continuous development of this technique has produced a new breed of instrument known as the infrared thermometer (Chakravorty, 1978). With this device it is possible to scan areas for evidence of temperature increases and systematic surveying with the instrument can allow trends to be developed and assessed.

To assess changes in the composition of the mine air has involved the use of carbon monoxide as a monitor. Mine air samples are taken from the general body of the ventilating air. This is normally done with hand pumps and sampling capsules on a regular basis e.g. once per 24 hours and the samples analysed in a laboratory, so establishing a system of intermittent monitoring. Each mine has a normal level of carbon monoxide emission and this "norm" needs to be assessed. The level of carbon monoxide can rise due to such mining operations as shotfiring or the use of diesel engines and, in assessing "norms," account must be taken of transient peaks from these operations. For the purpose of detecting a spontaneous heating it is essential to recognize a steady and continuous rise in carbon monoxide concentration. Professor Graham (1930) showed how the ratio of carbon monoxide

present to oxygen deficiency (compared to the proportion of oxygen to nitrogen in normal fresh air) is independent of changes in the ventilation rate. The Graham ratio of CO/O_2 deficiency has stood the test of time for heating detection and has proved not oversensitive to transient carbon monoxide peaks.

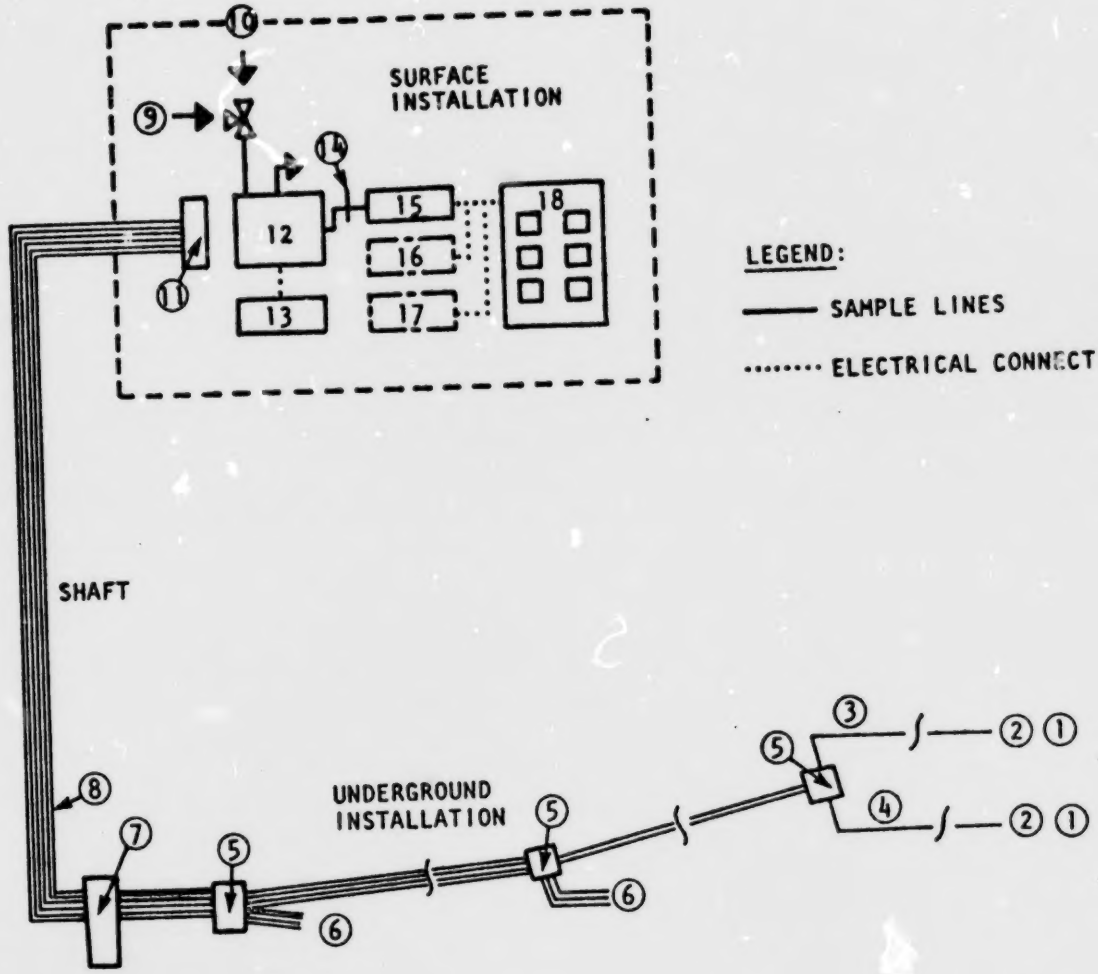
To use this ratio as an indicator, it is essential to first assess the "norm" ratio for each working area. As the quantity of carbon monoxide produced increases rapidly during a heating, the ratio is always a useful guide. Any significant increase in the ratio indicates abnormal conditions which require special investigation.

3.3 ENVIRONMENTAL MONITORING

It is internationally recognized that the prime method for the early detection of gob fires is by the continuous monitoring of carbon monoxide. Shaft monitors, to detect monoxide levels, have been in use at mines liable to spontaneous combustion for almost a decade. With this system, there are no underground sampling points and air entering and leaving the mine is monitored for carbon monoxide. A sustained increase in the concentration in the return air, in relation to the fresh air entering the mine, is indicative of abnormal conditions which warrant immediate investigation.

More recently, research has been directed towards "whole mine monitoring," where sensitive locations in the mine air circuit are continuously monitored (Chamberlain, 1973). The technique developed enables mine air samples to be brought continuously to the surface, from various parts of the workings, for analysis.

This technique, known as the tube bundle system (N.C.B., 1972), is shown on Figure 3. The system consists of multi-core tubes, usually up to 12 in number, housed within armoured hose, which are suspended through mine



1. DUST TRAP(S)
2. WATER TRAP
3. INTAKE AIRWAY
4. RETURN AIRWAY
5. JUNCTION BOX
6. BRANCH TO OTHER DISTRICT(S)
7. BANK OF WATER TRAPS
8. ARMOURED TUBE BUNDLE IN SHAFT
9. STANDARDISATION GASES
10. FRESH AIR
11. WATER TRAPS OR HUMIDIFIER
12. CONTROL BOX
13. TIMING CONTROLS
14. UNOR FINE DUST FILTER
15. UNOR CO ANALYSER
16. OTHER ANALYSERS
17. OTHER ANALYSERS
18. DISPLAY CABINET

FIGURE 3

SCHEMATIC LAYOUT OF A TUBE BUNDLE INSTALLATION

SOURCE: NATIONAL COAL BOARD, 1972.

DAMES & MOORE

roadways to the selected sampling sites. The tubes are channelled to an extractor pump on the surface which is adjacent to a gas analyser house. Each sample is analyzed for carbon monoxide, carbon dioxide, and methane by the infrared absorptiometric method and for oxygen by a paramagnetic method. Nitrogen is estimated by difference. The system is operated by a microprocessor which is programmed to calculate the Graham ratio and oxygen deficiency. The system can handle samples at the rate of one per minute, but of course the actual rate of sampling depends also upon the distance from the sampling point to the surface. Sample travelling time is of the order of 80 m per minute. The gas sample is first cooled and then passed through the gas analyser. Accuracy of the analysers is maintained by an automatic zeroing system that operates at the start of each sampling sequence and in addition known test samples are processed twice per day.

The tube bundle system serves the function of providing a full air analysis for the selected points. Analysis on the surface has several advantages. Sampling through the tube bundles can always be maintained, even when the supply of power to a district is cut off and men are withdrawn. The system can monitor a large number of points and can be extended almost indefinitely. Its major disadvantage is its slow response time which makes it unsuitable for outburst situations. This disadvantage can, to some extent, be overcome by moving the analyser underground and telemetering analysis results to the surface. This reduces the response time and allows the system to be used as a general fire alarm as compared with surface analysis which is only suitable for spontaneous heating alerts. A balance of the relative advantages and disadvantages for any particular mining situation must be made before final choice of system is determined.

Developing technology has made a reality of a computerised remote control and monitoring system (Corbett, 1979). One such data transmission system is depicted in Figure 4. These systems consist of three main elements:

1. Out stations, at selected points underground, to monitor the atmosphere to a computer via transducers

2. A surface primary computer which scans the out stations in a predetermined order. Information fed back from these stations is generated on a printer. An integral part of this computer is the control console with a function keyboard and twin monitor screens for graphic display. Also available are remote display terminals for use away from the central station

3. A secondary computer, of greater capacity than the primary, for long-term storage of data and feedback of information upon demand

Normally, production districts and development drivages will be monitored for:

1. airflow using as a transducer an instrument with three suitable velocity ranges
2. full air analysis
3. gas flow in the methane drainage range
4. gas purity in the methane drainage range
5. suction in the methane drainage range
6. smoke detection
7. combustible respirable dust levels
8. effective temperature
9. noise level indication

Additional functions, upon demand, would be calculation of the Graham ratio and visual display of the position of the sample in relation to the Coward triangle.

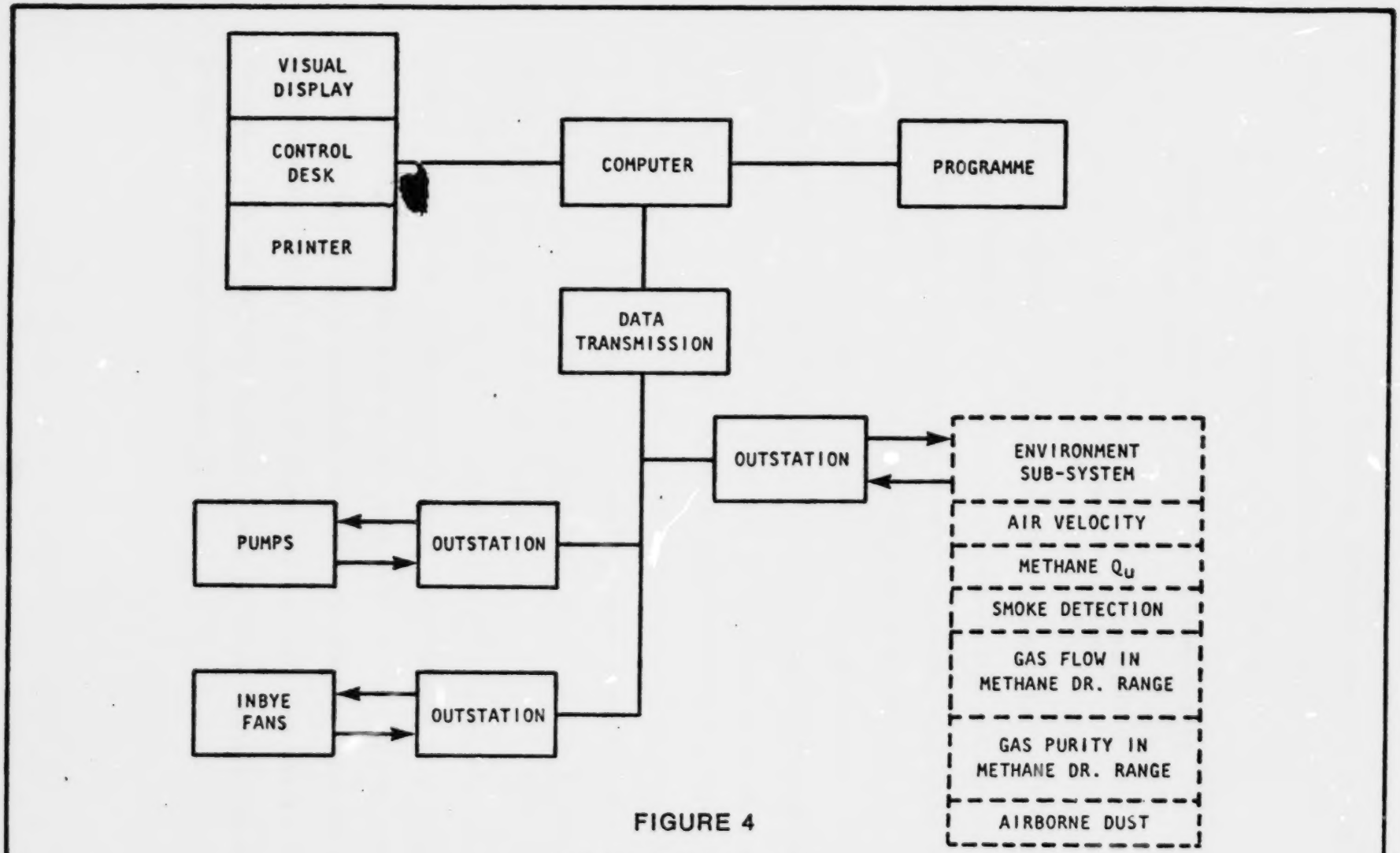


FIGURE 4

VENTILATION DATA
TRANSMISSION SYSTEM

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The transducers can be sited at selected sampling points and the layout for a typical production district is:

- outstation sited at intake entrance to district monitoring items 1, 2, 6, and 8 above
- outstation in primary working headings and monitoring selected items above
- outstation sited at the outer end of the district return provided with full range of monitoring facilities

In development drivages items are selected as appropriate.

Visual display units on the central control desk are the focal points for information fed back into the system. The normal display is a tabloid showing the monitoring point, identified by district name and location and the status of the various parameters being monitored. The tabloid represents the up-to-date underground condition and forms a general mine display. Other programmes are displayed as required, by typing the appropriate code on the function keyboard. The individual district display repeats the parameters covered by the general mine display together with district additional functions. Graphics can be established to display current shift, previous shift, and previous 7 days. In effect, they display trends which are on instantaneous recall.

One of the main uses of the system is the early recognition and indication of abnormal environmental conditions. The computer is programmed for parameter norms. Movement away from these norms is indicated by a series of alerts followed by alarm should the adverse trend persist. With the analogue transducers, several levels of alert can be indicated before alarm is reached. With the digital transducer, only an alarm condition is displayed as there is no graded circumstance.

All continuous monitoring systems have the advantage of providing early warning of abnormal developments in the environment and so allow for an early input of resources to correct the situation. As such, they are of particular value in combating the development of spontaneous heatings.

3.4 CONTROL AND ELIMINATION

With present mining technology and, given the premise that all coals can be considered liable to spontaneous combustion, elimination of the gob fire hazard does not appear feasible in the immediate future. The positive approach is to use mining methods which inhibit the onset of gob fire. These essentially are:

1. Adopt roadside precautions particularly for standing or slow moving working faces e.g. strata injection and use of sealants
2. Reduce obstructions at roadheads and near to the face to reduce the likelihood of leakage ventilation paths forming
3. Destroy, or seal around, coal pillars left in the gob
4. Remove as much remnant coal as possible, and also any foreign materials, from the gob
5. Take precautions in geologically adverse ground
6. Deflect air away from the gob in retreating districts
7. Keep the air quantity as low as other considerations will allow
8. Apply specific precautions at all locations where ventilation pressure drops are unavoidable and use pressure equalization techniques, if necessary

Little experimental work has been done on methods of suppressing gob fires. The safety factors involved determine the actions to be taken in any particular instance and devolve, almost entirely, about the experience of the mining engineers, on site. The following are the most usual alternatives to be considered:

1. Seal off all entrances to the fire zone using sandbags, rockdust, hardstop, latex, etc. Seals must be explosion-proof and their faces should be ventilation pressure balanced to minimise the supply of air to the heated zone (Staff, 1962)

2. If the heating is accessible and small in extent, the heated material may be dug out and quenched

3. The injection of inert gases into the fire zone

4. Complete flooding of the affected section if the physical features of the area are suitable

Experience will determine the method to be employed in any particular instance.

3.5 HEATING INCIDENTS

Gob fire incidents occur worldwide as the following examples indicate.

3.5.1 Bradford Colliery

A longwall advancing face, in a 1.4-m-thick seam, which had no previous history of spontaneous combustion, was encroached by a 1.8-m displacement fault which passed from the intake gate and onto the coal face. Fault grading on the face resulted in remnant coal in the fault zone being left in the gob. A gob fire developed and the district was sealed off. It was determined that the fault zone provided a leakage path from the intake roadway into the gob.

3.5.2 Wood Pit

An advancing longwall face, in a 2.1-m-thick seam sustained an extensive fall of roof at the intake roadhead. The fall took 1 week to clear before the unit could recommence production. Four months later, air samples showed a steady rise in carbon monoxide and a gob fire was located. Sealing of the roadway sides failed to control the situation and the district was sealed off. It was concluded that the obstruction caused by the fall resulted in a leakage air path being formed into the gob area, where remnant coal was present.

3.5.3 Sutton Manor Colliery

A retreat face in a 2.1-m-thick seam was working under the gob of a seam above. The rate of production was slowed as the unit neared its termination point. A gob fire developed and the district was sealed off. It was assessed that caving had resulted in interaction between the two gob areas and leakage ventilation was reaching remnant coal in the combined gob zone.

3.5.4 Rossington and Markham Main Collieries

A roadway connecting two mines was 7 km long and passed through an extensive area of partially mined coal pillars. Ventilation adjustments at one mine resulted in the repositioning of several sets of air doors in the pillared area. A gob fire developed in the pillared zone and attempts to restore the ventilation to its former condition failed. The roadway was eventually sealed at both ends and the seals were pressure-balanced and monitored to control the condition.

3.5.5 Brodsworth Colliery

A longwall face reached its termination point and salvage work was commenced. Difficulties were experienced with this work and several falls of roof occurred on the face line. After some 6 months, a gob fire developed and the unit was sealed off. The indications were that restrictions on the face had resulted in secondary air paths being established into the gob. The spontaneous combustion incubation period for this seam had been established as being 3 months. Salvage operations should have been completed within that period of time.

4. OPEN FIRES

The essential ingredients for a fire to be initiated are a source of ignition, combustible material, and a supply of oxygen. Whether or not an open fire is sustained and develops in intensity depends primarily on the intensity of the initiating source; the amount, flammability, and disposition of the fuel; the ventilation flow rate and the geometry of the mine roadway.

Two basic types of fire may be identified dependent on the rate of oxygen supply and the rate of oxygen reaction with the available fuel supply. When the oxygen supply is more than adequate to react fully with the fuel decomposed by the heat from the fire, the fire is said to be "oxygen-rich." Conversely, a fire is said to be "fuel-rich" when the oxygen supply is insufficient to react fully with the fuel decomposed by the heat (Roberts, 1969). Although the majority of open fires occurring underground are oxygen-rich it is possible for fuel-rich fires to result from the combustion of highly flammable materials such as polyurethane foam. Fuel-rich fires are associated with intense heat production in the fire zone and a severe oxygen deficiency immediately downstream of the fire.

4.1 SOURCES OF IGNITION

Thorp (1974) classifies the potential sources of ignition as follows:

1. the conversion of mechanical into heat energy; e.g. frictional heat generated by rotating picks striking rock or by defective conveyor idlers
2. the conversion of electrical into heat energy; e.g. sustained arcing
3. heat generated by chemical reaction; e.g. explosives, thermite reaction, smoking or spontaneous heating

The major cause of open fires has varied over the years. Open flames from lamps and other sources of illumination, from smoking materials, and

from gob fires which broke through into roadways, were dominant causes for many years. Today the majority of open fires originate from sources of frictional heat.

Frictional heat developed at the point of contact of cutting picks with coal, seam partings or intrusions, and roof or floor strata is impossible to avoid. However, the degree of risk associated with particular types of abrasive strata can be identified and the most appropriate measures implemented. In these situations the need to minimize the availability of combustible fuel will be the main concern. Mechanical and belt friction on belt conveyor systems are two of the main causes of fires in mines. Mechanical friction may be due to faulty or neglected machinery at driving heads, return drums and rollers having collapsed, unlubricated bearings or rubbing against obstructions. These situations give rise to frictional heat which often ignites coal dust in close proximity to the conveyor structure. It should be noted that the risk of coal dust ignition is inversely proportional to the size of the dust and very fine volatile dust may ignite at a temperature as low as 150°C. A common cause of this kind of fire is a bottom roller, with a faulty bearing, overheating and running buried in coal dust. Belt friction occurs at driving drums when the belt is stalled, or on drums, rollers and shafts where a strip of belt is being carried round and bearing tightly on another surfce, or where the belt is rubbing a stationary drum or roller. Several disastrous fires have been started when power has been restored to a conveyor district after a weekend shutdown. In these cases the conveyor motor starter has been left in the "on" position by accident or negligence and, during the resulting stall, frictional heat has been developed while no person is on the district.

The conversion of mechanical into heat energy is also the cause of fires in fluid couplings, compressors, and transportation and ventilation

machinery. Overloading and friction associated with the accumulation of combustible materials may give this equipment appreciable fire risk. Compressed air poses particular problems due to the possible issue from leaks creating local hot spots and the dangers associated with the accumulation of electrostatic charges.

The principal causes of fire associated with the use of electricity are open sparking and overheating due to arcing or overloading of conductors. These can arise from flameproof enclosures which are faulty or left open, a fault or break in a cable, or overloading a motor, transformer, cable, etc. One of the causes has been the repeated closing of switches tripped by overload leakage without full investigation as to the cause of the trip. Flexible trailing cables are particularly subject to damage from falls of ground, contact with moving parts, and abuse, leading to fusing and arcing.

Fires have resulted from the use of explosives through blown-out shots, due to overcharging and understemming, allowing the issue of flame to come into contact with combustible material. The use of aluminum and magnesium alloys has introduced the hazard which can result from the thermite reaction produced when a rusty steel surface smeared with light alloy or foil is struck a glancing blow with a steel object. Naked lights and smoking are the cause of fires resulting from carelessness where open lights are permitted, and from dangerous practices where they are not.

4.2 COMBUSTIBLE FUELS

Thorp (1974) separates the fuels that can be encountered underground into two categories as follows:

1. indigenous materials naturally present in the mine including methane, coal and coal dust, and occasionally oil
2. materials imported into the mine including timber, paper, flammable fluids and greases, and plastics

As the means of controlling a fire is dependent on the fuel involved Ritter and Gibson (1979) classify fires by reference to the fuel. Class A fires occur in ordinary combustible materials such as wood, coal, cloth, paper, and rubber. After combustion ash or residue remains. Class B fires occur in vapour-air mixtures over the surface of flammable liquids such as grease and lubricating oils or in flammable gas/air mixtures. All fires involving live electrical equipment are categorized as Class C. Class D fires are extraordinary and are associated with combustible metals.

Those materials naturally occurring in a mine have been responsible for the initiation of many open underground fires. By comparison, it is significant that the imported materials have usually been the medium through which a small fire in an underground roadway has developed into a severe one (Thorpe, 1974). It is well known that most materials burn more vigorously when they are ignited in surroundings in which heat is conserved and an air supply provided; a mine roadway is a typical example of such an environment. The effects of having materials burn in a ventilated duct have been described by Roberts (1970).

A Committee Report (1971) by the Institution of Mining Engineers reported that over a 5-year period the involvement of coal dust in mine fires was nearly twice that of any other material. Coal dust poses a special problem in that it can be ignited at a much lower temperature than any other material present near to the working face. The total rate of burning, and the rate of growth of fire in coal dust is low because it is very difficult to make coal dust burn other than by smouldering. It is therefore difficult to foresee circumstances in which a coal dust fire alone could so develop as to become a major threat. However, coal dust is a serious fire hazard because it provides a fuel in which fire breaks out on a small scale, may

continue undetected for a considerable period and then develops rapidly as other combustible materials become involved. In high production, intensively mechanized, working places there is generally more coal dust, combined with a better opportunity to start some of it smouldering, in the presence of other materials which are less easily ignited but more freely burning. Large, or solid, coal generally only contribute in a minor way to most mine fires especially in the early stages.

The extremely difficult circumstances which can arise with fire underground when methane is the main fuel have been described by LeBlanc (1976). Once ignited methane may continue to burn in the roof strata, in the gob, or in or adjacent to cross-measure methane drainage boreholes. A Staff Report (1962) of the Institution of Mining Engineers identified the specific problems associated with hanging flames in the gob. The main danger is that the presence and extent of any explosive methane mixture is unknown and there is the likelihood of an explosion occurring at any time.

Materials imported into the mine present a type of fire risk that is almost peculiar to the industry when the materials are used as roadway linings. Roberts (1969) described the fire risks associated with timber that had not been treated with a fire-retardant. It has been shown that intolerable conditions may result if untreated timber is ignited by a powerful source of heat such as would be provided by a fire in a substantial quantity of mineral oil; e.g., the Auchengeich Colliery fire, 1959.

The involvement of oil or grease in mine fires is a reflection of the number of fires started by frictional heatings on mechanical equipment. Mineral oils present the greatest hazard. While fire resistant fluids are available as substitutes in hydrostatic and hydrodynamic applications, mineral oils still find extensive usage for lubrication purposes.

Plastics, generally, have not been extensively involved in mine fires, the one major exception being the disastrous incident at Michael Colliery, Scotland (1967), involving polyuretnane foam. Plastics do not necessarily burn in the same way as cellulosic materials such as wood, and special methods for examining their fire hazard in a mining environment may have to be developed. Although most conveyor belt in use is fire-resistant it is not incombustible and will contribute to a fire in other materials. Its potential contribution to fire on or near high production faces cannot be ignored.

4.3 CHARACTERISTICS OF FIRES

While the chemical process of combustion is the same in principle no matter where the burning takes place, the effects of a fire occurring underground can be widely different from the effects of a fire involving the same combustible substances in the open atmosphere at the surface.

Where coal is burning underground there is free flaming in the early stages, accompanied by the emission of large volumes of smoke and tarry vapours. On the return side of the fire the oxygen content of the atmosphere is reduced and the carbon dioxide content increased. The presence of carbon monoxide is inevitable. The actual toxicity of the atmosphere can be determined only from a chemical analysis of the gaseous constituents.

In the case of fire in the timber lagging of a mine roadway, the volatile products from the heated wood mix with the ventilation air, and react with the oxygen present, giving rise to flames. The air current is heated by this process and its oxygen is progressively replaced by products of combustion. After passing through the fire the fumes pass along the roadway causing some heating of the lagging ahead of the fire as it does so (Roberts, 1969). Unless diluted at a ventilation junction the fumes remain of constant composition and slowly cool to the ambient mine temperature. The rate of

oxygen supply and the rate of oxygen reaction with the fuel supply determine whether the fire is "oxygen-rich" or "fuel-rich." Roberts (1969) reports that a fire in timber lagging, ignited by a small source of ignition, is unlikely to accelerate spontaneously to the fuel-rich condition. The reasons for this are the length of time required for such a fire to develop and the changes in circumstances of the fire caused by roof falls, short lengths of incombustible lining, or through fire control measures. However, the fuel-rich condition may be approached in the event that there is an intense igniting source or a reduction in ventilation quantity.

The behavior of fires in untreated polyurethane foam linings has been described by Wilde (1968). A polyurethane foam fire achieves a fuel-rich condition very rapidly, giving rise to high temperature levels with the production of gas concentrations similar to those associated with fuel-rich fires in timber lagging, along with the addition of toxic concentrations of hydrogen cyanide.

The characteristics of a fire are important in determining the measures which should be adopted to control the incident. Fuel-rich fires necessitate the use of self contained breathing apparatus on the return side as the atmosphere contains less than 5 percent oxygen and is intolerably irritating to the eyes. The return atmosphere is virtually opaque and intolerably hot for at least 1,000 m outbye the seat of the fire. The rapid rate of fire advance influences the sites chosen for seals should stopping off be necessary. In addition the excess fuel contained in the products of combustion could encounter additional fresh air at a ventilation junction and become explosible. In any situation where fire control is attempted through a reduction in ventilation flow rate the possibility of development of a fuel-rich fire is a major consideration.

4.4 DEVELOPMENT OF FIRES

The manner and speed with which a fire can develop and spread, the effect of fire on the ventilation, and the effect of ventilation on the fire are fundamental factors in determining the best way to control the incident.

Progressive development of a fire involves the production of smoke, high atmospheric temperatures and toxic gases. The density of smoke depends on the intensity of the fire and the materials involved. Very little smoke is needed to obscure vision in an underground roadway and to be unpleasant to men. The difficulty of coping with high temperatures is often aggravated by high humidities resulting from the use of fire fighting water. The generation of toxic gases depends on the intensity of the fire and the types of materials involved. Atmospheric hazards may be compounded by severe oxygen deficiency and excessive carbon dioxide on the downwind side.

Development of the fire may be accompanied by loss of competency of materials used for support resulting in falls of roof. Falls can seriously affect the spread of a fire and may impair fire fighting.

Generally, the main combustion zone travels in the same direction as the ventilation. The effect of an open mine fire on the ventilation depends upon the heat generated by the fire which in turn depends on the intensity of the fire, the materials involved, and the mine geometry (Thorp, 1974). Temperatures reached may attain 800°C for a severe mine fire involving timber lagging, while local temperatures exceeding 1000°C may be achieved with mineral oil fires. Small open fires do not generally affect the stability of the main ventilation. Severe fires may exert a constricting or buoyancy effect.

A constricting effect on the ventilation in the fire zone is brought about by an increase in ventilation volume resulting from expansion and the addition of fire gases. The increased air volume in the roadway immediately downwind of the fire requires additional ventilation pressure to maintain flow or flow is reduced. The ventilation pressure required to maintain flow and overcome the constriction effect may be calculated and is dependent on the mean upwind and downwind absolute temperatures. However, as downwind temperatures normally decrease fairly rapidly the constriction effect is limited to the vicinity of the fire and is likely to be small in relation to the normal ventilation pressure and compared to the buoyancy effect in inclined roadways. The constriction effect always opposes the ventilation flow.

The buoyancy effect in an inclined roadway results from the increased temperature on the downwind side of a fire reducing the air density. The density difference across the fire zone creates a pressure difference, known as the buoyancy effect, which assists the ventilation in uphill roadways and opposes it in downhill roadways. The buoyancy effect is directly proportional to the difference in air densities and the vertical height over which the low density atmosphere exerts an influence. The important parameters are therefore the roadway gradient and the rate of fall off of the downwind temperature.

The combined effect of constriction and buoyancy must be considered in relation to the prevailing situation at each particular fire zone. In the case of an intake fire in a downhill ventilated roadway their combined effect is to oppose ventilation and reduce flow. If the buoyancy effect is sufficiently large there is a danger of ventilation reversal, leading to progressive fire development in both directions, and the danger of the

fire becoming inaccessible for fire fighting purposes. A similar situation in an uphill ventilated intake results in increased airflow which may require regulation.

In the case of a fire occurring in one of a pair of parallel intake roadways, whether they are downhill or uphill ventilated, a variety of alternative solutions to control the development of the situation is possible. The main consideration is to avoid the danger of ventilation reversal and "backing-up" of the combustion products while maintaining the normal direction of airflow without oversupplying air.

The development of a fire adjacent to or on a longwall face poses similar problems to those previously referred to. The situation is aggravated by the presence of gob, which may be methane-filled, and the existence of active methane feeders from the seam or surrounding strata. Seam inclination, and whether ascensional or descensional ventilation is being practised, are important factors influencing development of the fire zone.

4.5 LOCATION OF FIRES

Very few fires start on longwall faces (Committee of the Institution of Mining Engineers, 1971). The majority of fires occur on intake roadways and, as a result, the downwind intakes, face, and returns are contaminated by fumes, smoke and the products of combustion. The extent of life at risk is therefore considerable. However, access to the site for fire fighting should be good and there is generally no risk of methane being passed over the fire over than in a descensionally ventilated situation.

In the event that a fire occurs in a return the intakes and working places will not be contaminated by smoke and fumes, thus assisting in the safe withdrawal of men. However, fire fighting must be carried out from inbye, that is through the working face, and methane emitted inbye passes

through the fire zone. It is therefore essential to maintain ventilation at a sufficiently high level to ensure adequate methane dilution without over supplying air.

4.6 FIRE DANGERS

Underground fires pose a most serious hazard due to the limited escape routes available to personnel. The mining legislation of different countries requires fire precautions to be implemented in a variety of ways. While the majority of legislation focuses attention specifically on the prevention and control of fires, United States legislation (U.S. Government, 1969) requires, in addition, the provision of "escapeways," which are maintained in addition to the intake and return roadways.

The majority of deaths occurring during mine fire incidents result from asphyxiation and smoke inhalation. As a result the mandatory use of self-rescuers is required in most mining countries.

The danger of any mine fire causing an explosion is dependent on fire location, source of fuel and local mine conditions. The advisability of attempting to fight fires in locations where there is a chance of explosive mixtures of methane or fire gases being present, requires rigorous detailed consideration. An early decision to seal off the incident can result in reduced exposure to accident and the loss of minimum mine area.

5. OPEN FIRE PREVENTION, DETECTION AND CONTROL

5.1 PREVENTION AND PRECAUTIONS

5.1.1 Frictional Heat

It is impossible to eliminate frictional heat being generated where cutting picks on a machine impact coal or the surrounding strata. The essential requirements are, therefore, to minimize the risk of ignition and, in the case of an ignition occurring, eliminate the risk of an explosion or serious fire. Precautions include the identification of those locations where there is a potential frictional ignition problem associated with abrasive and/or quartzitic roof and floor strata or the presence of similar rock types in the seam. The selection of mining method, and power loader or other machines, needs to be cognizant of the potential problems. Provision of adequate ventilation, with positive ventilation of fast ends or blind corners, is a vital requirement associated with water supply, at adequate pressure and in adequate quantity, at the pick point. Particularly hazardous locations, such as geologically faulted areas and the return end of longwall faces, should be identified and considered in the mine layout and operational design.

To avoid frictional heat development on belt conveyors, system design, engineering, installation and maintenance require attention. The use of open-type structure is preferable and a systematic program of belt patrolling and inspecting is necessary. Conveyor driveheads should be equipped with devices to monitor belt slip, torn belt, belt alignment, "sticky" brakes, overheating and blocked chute.

5.1.2 Mechanical and Electrical Equipment

The avoidance of fire risks requires detailed attention to the design, installation, transportation, inspection and maintenance of all underground

equipment. This particularly applies to mobile equipment and equipment which has a more than average risk e.g. compressors, diesel equipment, and all appliances containing hydraulic circuits. Although potential sources of fire should, as far as practicable, be eliminated at the design stage protective devices should be in-built to the fullest possible extent. Protective devices include overload protection, sensitive earth leakage, thermostatic switches, fusible plugs and the use of nonflammable fluids and antistatic materials.

Thorough and adequate training of mechanical and electrical personnel is fundamental.

5.1.3 Blasting

Strict adherence to existing legislative requirements is necessary with particular attention to proper charging and stemming procedures. Thorough precharging examinations are necessary to ensure that danger does not result from methane layers or methane accumulations in cavities. The exercising of personal responsibility by the person authorised to carry out blasting operations is probably the most important preventive measure.

5.1.4 Fuels

Good standards of mine ventilation are an essential prerequisite if fires are to be avoided. Apart from the emphasis which it is necessary to place on adequate methane dilution in the general ventilation, the potential hazards associated with methane layers and methane accumulations, in locations where the general ventilation methane dilution is good, should be recognised. The use of methane drainage techniques should be applied where necessary.

Avoidance of accumulations of fine coal dust should be avoided by the institution of regular cleaning up procedures particularly in those

locations where dust regularly occurs. If it is not practicable to clean up coal dust, adequate dilution with rock dust is necessary to ensure that the mixture is nonflammable.

All combustible materials taken below ground should be fire resistant wherever possible. This includes conveyor belting, brattice cloth, timber, electric cables, hoses, V-belts, sealants, flexible ventilation tubing, etc. Mineral oil should be replaced by fire-resistant fluid. Fire-resistant materials only should be used in locations with high fire risk e.g. conveyor belt transfer points, and the objective should be to make these places fireproof.

The use of aluminum and magnesium alloys should be avoided due to known hazards resulting from thermite reaction. The use of metallic foil for any purpose underground should be prohibited.

5.1.5 Barriers

Both rock dust and water barriers have been shown to have played active roles in limiting the spread of flame from explosions (Eisner, 1964). Their provision in strategic locations in a mine is an important precautionary measure to guard against the dangers resulting from explosion or fire.

5.1.6 Preparatory Seals

In mines identified as having a particular fire hazard the provision of sites, where the initial preparatory work for a seal has been commenced, is desirable. The supply of materials at the site should be sufficient to allow rapid completion of the final seal.

5.2 DETECTION

The identification of effective fire detection systems to provide early warning of fire has been a continuous research topic in the mining

industry. The Committee on Mine Ventilation (1971) reports that the use of smoke detectors has not been popular in the past because of the high proportion of false to genuine alarms. As a result of the major fire hazard in South African gold mines, van der Walt (1976) records details of the intensive investigation of underground fires commenced by the Chamber of Mines in 1973. One major project to emerge from the findings was the design of an effective fire detection system. Van der Walt summarizes the requirements of a detection system to be continually monitoring, detection of fire within minutes of ignition, identification of fire location, reliable under difficult environmental conditions, applicable to extensively developed mines, easy installation, long life, and minimal and simple maintenance. The difficult environmental conditions anticipated at the detection sites included hot and humid conditions, high air velocities, and airborne dust concentrations.

Bout (1970) identifies the senses of smelling, seeing and feeling as being the main human means of fire detection and he classifies the physical detectors as temperature, optical and ionization. Temperature detectors depend on rate of temperature increase, or absolute temperature measurement, for their operation. Use is made of thermocouples, thermistors or bimetallic strips to break an electrical circuit at a predetermined set condition. Optical dectors normally depend on photoelectric devices to operate alarm circuits when smoke is present. Van der Walt (1976), in work for the Chamber of Mines of South Africa, favours the ionization detector. This device operates on the principle that when combustion particles enter a chamber, in which a minute electric current passes through ionised air, the current flow is reduced.

Operational experience and tests with ionisation detectors are reported by Hemp (1970). To be effective detectors must be sited in the most advantageous position at the most vulnerable locations. They must be capable of automatically activating fire suppression equipment, or be linked to an efficient communications system to enable immediate remedial action to be taken. Whatever the type of detector and method of operation selected, time is a fundamental factor and a speedy reaction to any outbreak of fire is essential.

5.3 FIREFIGHTING AND CONTROL

McPhail (1975) identifies three organisational components as necessary to achieve control over a fire together with the safe evacuation of personnel, namely, fire procedure, fire organisation and fire control. The procedure to be followed in the event of fire defines the duties and movements of all personnel including those of the person discovering the fire. The organisational plan specifies the duties and responsibilities of supervisory personnel to coordinate all services toward efficient rescue of men and extinguishing of fire. Fire control is the focal point where policy and plan decisions are made during the incident.

The specific method of dealing with a fire depends on the extent of the conflagration, location, type of fuel, number of men at risk, ventilation and the mine geometry. A fire can be extinguished by either cooling the burning mass below the temperature of ignition or separating the fuel from the oxygen. The application of water to the burning surface of wood or coal is the best known method of arresting combustion, especially if the water is applied with force in the form of a jet. Refined methods of breaking up the water into droplets of a particular size are usually not necessary, as it is the solid part of a water jet which is most effective provided adequate

coverage of the fire ground is maintained. Mineral oil fires can be safely and successfully fought with water sprays provided that the water is supplied, at a rate matched to the maximum potential size of the fire, in sufficiently fine droplets (Rabash, 1962). Water cannot be safely used on electrical fires, particularly where high voltages are employed, until the power is switched off. Where electrical equipment is present in a fire which mainly involves oil the best extinguishing agents are rock dust, and carbon dioxide, low-expansion protein foam and dry powder. There are many descriptions of the properties of materials in the literature (Stark, 1968). Medium- to low-expansion foam is the best firefighting medium for automatic systems designed to deal with oil fires where electrical equipment is not present. The advantages of foam over dry powder are that it is able to flow around obstructions, hence avoiding the need for accurate direct attack, and it forms an air-excluding blanket over the liquid surface which effectively prevents reignition.

While small fires should be immediately directly attacked with the appropriate extinguishing agent, the development of a large fire will require plentiful supplies of water at high pressure. Immediate attack is from the intake side until suitably equipped personnel are available to attack from downwind, where the main aim is to construct a fire barrier to limit spread. When it is not possible to extinguish a fire by direct attack control may be achieved by flooding, where the fire location and seam geometry are favourable, or by sealing off. Seals may be constructed from imported materials, or water where low-lying locations exist. Considerations relating to the selection of seal sites, types of seal, seal stability and the need for ventilation pressure-balancing on the face of the seal, apply in this situation similarly to their application in the control of gob fires.

5.4 FIRE INCIDENTS

The very serious hazard posed by mine fires is evidenced by the numerous technical papers on the subject found in mining literature. The following incidents, which have been abstracted from the referenced sources, are described to illustrate the dangers which can arise in different mining situations.

5.4.1 Auchengeich Colliery

This incident occurred in Lanarkshire, Scotland and was the subject of Ministry of Fuel and Power Report Cmd 1022 (1960). Auchengeich, a gassy mine, produced approximately 660 tonnes per day from the Meiklehill Main Coal and Kilsyth Coking Coal Seams. These seams were intersected by two main roadways driven from the shaft bottom. While the intake roadway was used for coal transportation, the return roadway contained a rope hauled manriding haulage.

Mine ventilation was assisted by a booster fan sited in the return roadway approximately 1550 m from the shaft bottom. The booster was a double inlet, forward-bladed, radial flow fan with a 1.1-m-diameter rotor driven by a flat belt. This transmission belt was 300 mm wide made of high-tensile cotton duck and balata gum, neither of which is fire resistant. The fan was sited on the return roadway centre line with its outlet casing mounted in a brick wall across the roadway. Apart from brick-lined fairings the roadway immediately adjacent to the fan was lined with timber which was not fire resistant.

The outbye man-riding haulage was an endless under-rope type comprising four bogies each seating 12 men. The electrically driven engine was housed in the return airway.

Fire was first detected on the early morning shift when the operator of the man-riding haulage engine detected haze and a slight smell of burning. About 17 men were hauled inbye in the thickening haze, some of whom alighted and, via an outbye cross-cut, entered the intake roadway. After travelling inbye for a short distance they were able to gain access to the fan site through a second set of ventilation doors. Flame was observed rising from the transmission belt, which had burned through, oil was burning around the bearings, and flame was issuing from the fan outlet.

Immediate attempts were made to fight the fire with sand and rock dust as the available fire extinguishers were out of order and hoses were not immediately available. Unfortunately the fire quickly spread to the roadway outbye the fan and defied the attempts to bring it under control. Danger was also appreciably increased when it was obvious that, the reduced inbye airflow had allowed methane concentrations to increase, resulting in methane-air mixtures near to the lower explosive limit being present in the fire vicinity. Coincident with firefighting operations being carried out, and due to a tragic misunderstanding in communications, a full train of 48 men started inbye towards the fire in an atmosphere containing lethal concentrations of carbon monoxide. Only one of these men survived. The final decision was made to seal off the area using water seals placed at low-lying points in the main roadways outbye.

It was subsequently concluded that the fire originated through the development of frictional heat between the fan transmission belt and the driving pulley when the belt fell off and became jammed. Development of the fire was accelerated by the presence of flammable oil and timber. The need for adequate, properly maintained firefighting equipment at vulnerable locations, speedy and effective communications, and the provision of self-rescuers were also highlighted.

5.4.2 Cambria Mine No. 32

This fire occurred in western Pennsylvania and is reported in "Coal Age," 1977.

Cambria Mine No. 32 formed part of an underground complex to which two other mines were connected. None of the mines had been in production for several weeks prior to the incident and only maintenance workers and patrolling supervisors were present at the time it occurred. It was believed that the fire began when a roof fall caused a bare overhead trolley wire to short out, igniting nearby timber and coal. Direct attack failed to bring the fire under control and it spread across several entries in the first few days. The fire subsequently became the focus of considerable attention as a variety of techniques were used to bring it under control.

Initial firefighting attempts were made using water and foam but these failed due to the production of hydrogen and carbon monoxide in dangerous concentrations. While direct attack was maintained over a 3-week period boreholes were drilled down from the surface to intersect the entries. Although the intention was to remotely seal from the surface by fly ash blown through the holes, this was finally considered to be unpracticable due to roof falls creating very large cavities and the difficulty of injecting dry fly ash. As a final resort the mine was flooded between 8 seals with 550 million litres of water.

The duration of the firefighting operations was 2 months and although, fortunately, no personal injuries resulted the estimated loss in production revenues was $14 million.

5.4.3 Mars No. 2 Mine

The disastrous consequences that can result from ventilation changes under fire conditions were well illustrated during this incident in West

Virginia (Colliery Guardian, 1966). Approximately 700 litres of mineral oil in a piece of equipment were ignited by an electrical discharge. During the subsequent firefighting operations the main fan was stopped, whereupon large quantities of smoke and fumes backed up against the ventilation driving firefighters away from the seat of the fire. The fan was restarted and an explosion then occurred which travelled over a considerable distance.

One explanation which was formulated was that when the fan was stopped the oil continued to burn in a very restricted air supply, and excess oil was vapourized in fuel-rich conditions. When the fan was restarted the additional air supply mixed with the fuel-rich fumes from the fire giving an oil vapour/air mixture of considerable volume which was then ignited by the flames from the original fire.

5.4.4 Ogilvie Colliery

Located in northern Glamorganshire, Wales, Ogilvie Colliery was connected underground with the adjacent McLaren Colliery (Robinson, 1972). Thus three shafts and two main fans were involved in providing ventilation of the mine which was regarded as slightly gassy. Three longwall faces were in production at the time of the incident.

During a routine weekend inspection smoke was observed in a roadway near to the upcast shaft bottom. Almost simultaneously smoke was noticed in the surface fan drift, and the fumes which soon were emitted from the evasee suggested that a substantial fire was burning underground. Rescue teams were quickly mobilised but they failed to locate the seat and extent of the fire due to dense smoke and intense heat which had "backed" against the ventilation. The Incident Control Committee which had been formed, considered the various alternatives available to ascertain the extent of the fire zone and to bring the fire under control based on the results of air analysis.

It was finally decided to stop the Ogilvie mine fan and to sustain ventilation in the mine using the McLaren fan alone. It was only discovered later that because of numerous inter-shaft connections part of the upcast shaft was upcasting and part was downcasting. By judicious adjustment of ventilation pressures such that airflow over the fire area was reduced, and access to the fire was improved, the fire was eventually brought under control by direct attack with water.

The incident illustrated that with prompt action, effective organisation, detailed consideration of the site-specific mining factors and decisiveness it is possible to control a rapidly developing fire. A period of 91-1/2 hours elaspsed between the first observation of smoke and the fire being brought under control.

5.4.5 Thurcroft Main Colliery

Chapman (1972) reports details of this ignition and fire in Yorkshire, England. The longwall face on which the incident originated was extracting the Haigh Moor Seam which was 1.39 m thick. Equipped with powered supports the face had only been in production for 2 weeks prior to the ignition. The seam was classified as slightly gassy.

The original ignition occurred when, following the firing of 11 holes at the return roadway brushing, a sheet of flame appeared and was seen to travel outbye along the roadway. Immediate action was taken and the flames were quickly brought under control by the application of water and the use of fire extinguishers. However, an examination of the affected area revealed "rumbling" in the gob and the intermittent issue of smoke from a point in the roof. It was decided to evacuate all men from the mine.

Within 2 hours the decision had been made to seal off and these operations were commenced. Two 8-m-long seals, constructed of sandbags reinforced

with steel, were erected during the next 35 hours. The return seal was fitted with a pressure chamber in order to allow partial pressure equalization on the face of the seals. Following the evacuation of men from the mine, observations of carbon monoxide content of the upcast air were recorded by UNOR gas analyser to enable progress in the sealed area to be ascertained.

During the following days a number of peak emissions of carbon monoxde were shown on the UNOR recorder trace and it was concluded that each represented a further ignition in the sealed area. This was confirmed by underground inspections which revealed blast damage to the seals. As a ventilation pressure difference between the face of the seals was in existence it was decided to equip the intake seal with a pressure chamber, to reduce the ventilation pressure in the mine and to achieve improved pressure equalization between the seals. This was not fully effective due to the damage which had been caused to the return seal creating airflow leakage paths. Subsequent repair of the seal, and the use of sprayed sealants, allowed pressure equalization to be more effectively realised and air analysis showed the gradual build-up of an extinctive atmosphere.

Thirty-four days after the first ignition the sealed area was reopened by the direct ventilation method with all men evacuated from the mine. Subsequent investigations revealed considerable damage in the face return roadway. However, it was possible to recommence production 21 weeks after the original ignition during which time there had been no serious personal injury.

6. CANADIAN MINE FIRE EXPERIENCES

Information relating to mine fire experiences, fire precaution and control procedures, and ventilation practices was obtained during discussions with mine operators and from mine visits. The mines visited for the purpose of this study were:

No. 26 Mine, Cape Breton Development Corporation, Nova Scotia
Lingan Mine, Cape Breton Development Corporation, Nova Scotia
Balmer South Mine, Kaiser Resources Ltd., British Columbia
Somerset Mine, U.S. Steel Corporation, Colorado

In addition, the following mines were visited recently in association with other studies:

Canmore Mines, Canmore, Alberta
Vicary Creek Mine, Coleman Collieries Ltd., Alberta
No. 5 Mine, McIntyre Mines Ltd., Alberta
No. 2R (Reiff Terrace) Mine, McIntyre Mines Ltd., Alberta
Atlas Mine, Century Coals Ltd., Alberta
Star Key Mine, Inland Cement Industries, Ltd., Alberta
York Canyon Mine, Kaiser Steel Corporation, New Mexico
Sunnyside Mine, Kaiser Steel Corporation, Utah
Emery Mine, Consolidation Coal Company, Utah
Lincoln Mine, The Imperial Coal Company, Colorado
Dutch Creek Mine, Mid-Continent Coal & Coke Company, Colorado
Stansbury Mine, Stansbury Coal Company, Wyoming
Vanguard Mine, Energy Development Company, Wyoming
Balmer North Mine, Kaiser Resources Ltd., British Columbia

Canadian mine fire experiences are more directly related to and associated with the extraction method employed rather than with geographic location. Experiences are hence discussed in this report by reference to hydraulic, longwall and room-and-pillar mining methods.

6.1 HYDRAULIC MINING

Hydraulic mining is being practised in Canada only at the Balmer South Mine of Kaiser Resources Ltd. located near Sparwood in southeast British Columbia.

6.1.1 Balmer South Mine

6.1.1.1 General Geological Details

This operation has been described in detail in the technical press (Parkes, 1975; Fish, 1978). A fairly detailed description of the operation is given in this report since, for reasons which are made clear later, it is the inherent problems of mining a very thick friable coal seam rather than the specific characteristics of the coal itself, which appear to be responsible for the spontaneous combustion incidents experienced to date.

This mine extracts the No. 10 Seam which outcrops in the floor of the Michel Creek valley at an elevation of 1280 m. The outcrop has been traced for several kilometers at elevations up to 1600 m along Sparwood Ridge. The strata are comparatively uniform and consist of competent shales, sandstones, and siltstones. The coal is friable by international standards though it is stronger than many of the other seams in the Rocky Mountains. The compressive strength of the coal ranges from 6.7 to 16.75 M Pa.

The depth of cover over areas extracted to date has ranged from 0 to 300 m. Areas being developed for extraction in the next few years will be mined at depths up to 500 m.

The No. 10 Seam averages 15 m in thickness. Due to the uniformity of the strata little exploration drilling has been done. Because of this, and the unusually thick seam, variations in coal thickness have not been well defined. The gradient varies from 25 to 55 degrees with an average of 30 degrees and the seam dips almost due south. Faulting has not been a significant factor in mine design.

The coal is low to medium volatile bituminous. A proximate analysis of a typical channel sample on an "as received" basis is:

Moisture	0.3 percent
Ash	9.0 percent
Volatile matter	19.0 percent
Fixed carbon	71.7 percent
Sulphur	Generally less than 0.5 percent

6.1.1.2 Mine Layout and Production

The layout of Balmer South Mine is shown on Figure 5.

The original hydraulic operation was opened up from the No. 1 flume road and the belt road. The flume road was driven in coal from the outcrop at an alignment to the strike which produced a gradient of 7 degrees dipping outbye. As the gradient of the seam changed, the alignment of the flume road was altered to provide a constant gradient in the roadway of 7 degrees. This flume road and a companion drivage were utilised for most of the coal mined in panels 1, 2, 3, and 4.

Before these panels were exhausted, No. 1 rock tunnel was driven at a rising gradient from a point on the surface to intersect No. 10 Seam approximately 300 m to the low side of the No. 1 flume road. From this point, a flume road (known as No. 1 entry) was driven 1500 m to open up panel 5 which was then extracted in three sections 5A, 5B, and 5C.

The system of development and extraction of panels can be illustrated by reference to panel 5C on Figure 5. The panel is developed by a series of sublevels driven in coal at a horizon just below the midpoint in the seam. The sublevels are driven from the dip to rise and are between 180 m and 300 m long. Sublevels are driven parallel and approximately 25 m apart. The alignment of sublevels is arranged so that the gradient is approximately 7 degrees.

It is important to note the order of extraction. In panel 4 the area known as panel 4B was mined before 4A and this is thought to have been a contributing factor in subsequent heating problems. When the next area was mined, panel 5A was mined first, then 5B and finally 5C.

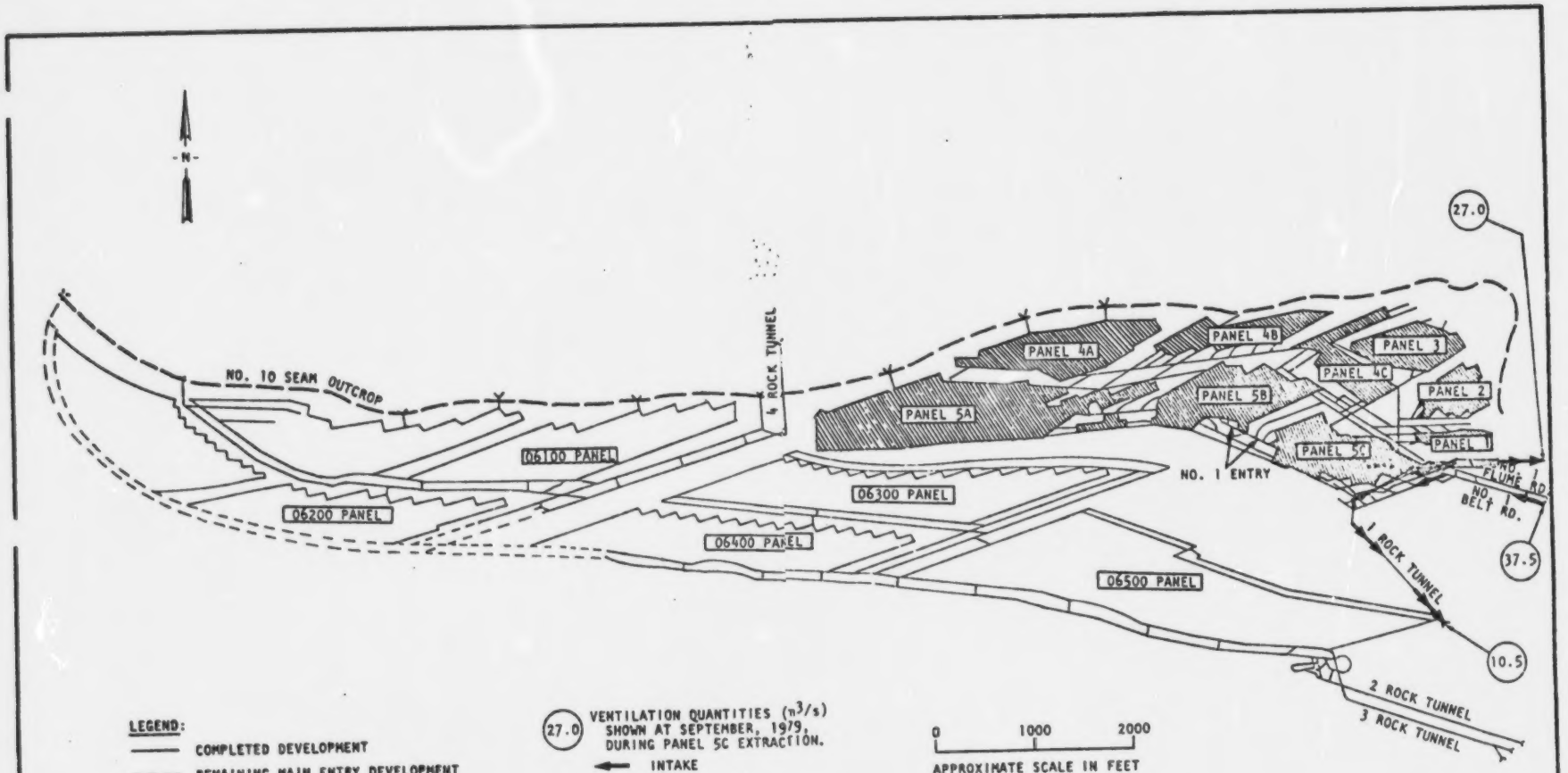

FIGURE 5

BALMER SOUTH MINE
NO. 10 SEAM MINING LAYOUT

DAMES & MOORE

SOURCE: KAISER RESOURCES LIMITED, 1979.

The chronological order of panel extraction has been:

Panel 1 October 1970-April 1971
Panel 2 May 1971-December 1971
Panel 3 November 1971-August 1972
Panel 4B September 1972-April 1973
Panel 4A May 1973-July 1974
Panel 4C August 1974-February 1975
Panel 5A January 1975-March 1977
Panel 5B March 1977-May 1978
Panel 5C May 1978-to present

All roadways are driven by ripper-type continuous miners. Coal from the development is sometimes transported to the flume road by shuttle car. Alternatively, water is used to transport coal in flumes located behind the miner. Most roadways are supported by steel arches at 1.5-m centres surrounded by 50-mm-thick lagging boards. A substantial quantity of timber is required for blocking and cogs above the lining.

Extraction of the 25-m pillar between each pair of sublevels is by hydraulic monitor. The monitor is mounted on a feeder breaker consisting of a chain conveyor on which a lump breaker and a winch are mounted. Coal broken by the water jet is flushed by water across the floor of the working area to the feeder breaker which discharges into the flume. All coal from panels mined to date has been above drainage and has been transported to the surface entirely by flumes.

Three or four sublevels are equipped with monitors though only one is in operation at any given time. A labour force of 160, including underground and surface personnel, has produced up to 900,000 raw tonnes annually.

Recovery of the in situ coal is difficult to measure as the exact seam thickness is not generally known. Hydraulic mining has resulted in appreciably higher recovery rates than any conventional method used in the same seam. It has been estimated that recovery of coal within the

area mined by a typical panel is approximately 50 percent. After allowing for pillars left between panels and along the outcrop the overall recovery is approximately 25 percent.

6.1.1.3 Ventilation Details

Ventilation requirements have varied during the life of the mine. The No. 10 Seam in Balmer South has not, in the area developed and extracted to date, given off measurable quantities of methane. However, development roadways below drainage, where pillar extraction has not yet commenced, have given emission rates of 0.26 m^3/s.

At present only one monitor is operating, recovering coal in pillars near the end of No. 1 rock tunnel. Figure 5 shows the ventilation arrangements. A single-forcing fan handling 37.5 m^3/s utilizes No. 1 flume road and the belt road as intakes. The majority of the return air, 27 m^3/s, returns through the gob to the outcrop. The balance, 10.5 m^3/s, is exhausted via the No. 1 rock tunnel.

This ventilation system is not typical as only one monitor is operating at present. Since ventilation management is a critical factor in the prevention and control of spontaneous combustion it is pertinent to describe the ventilation arrangements which have been utilized at different stages of the operation. At the time panel 5A was being extracted two forcing fans were utilized to circulate 75 m^3/s. Intake air was divided between the entries on the low side of the No. 5 panel and those on the high side. The air was split to ventilate sublevels under development and those where monitors were operating (Figure 6). Return air from the faces was allowed to ventilate the gob of panel 5A and 54 m^3/s returned to the surface through the adit connecting the panel with the outcrop. Approximately 13.5 m^3/s returned through No. 1 rock tunnel. A similar system of ventilation, using the gob as

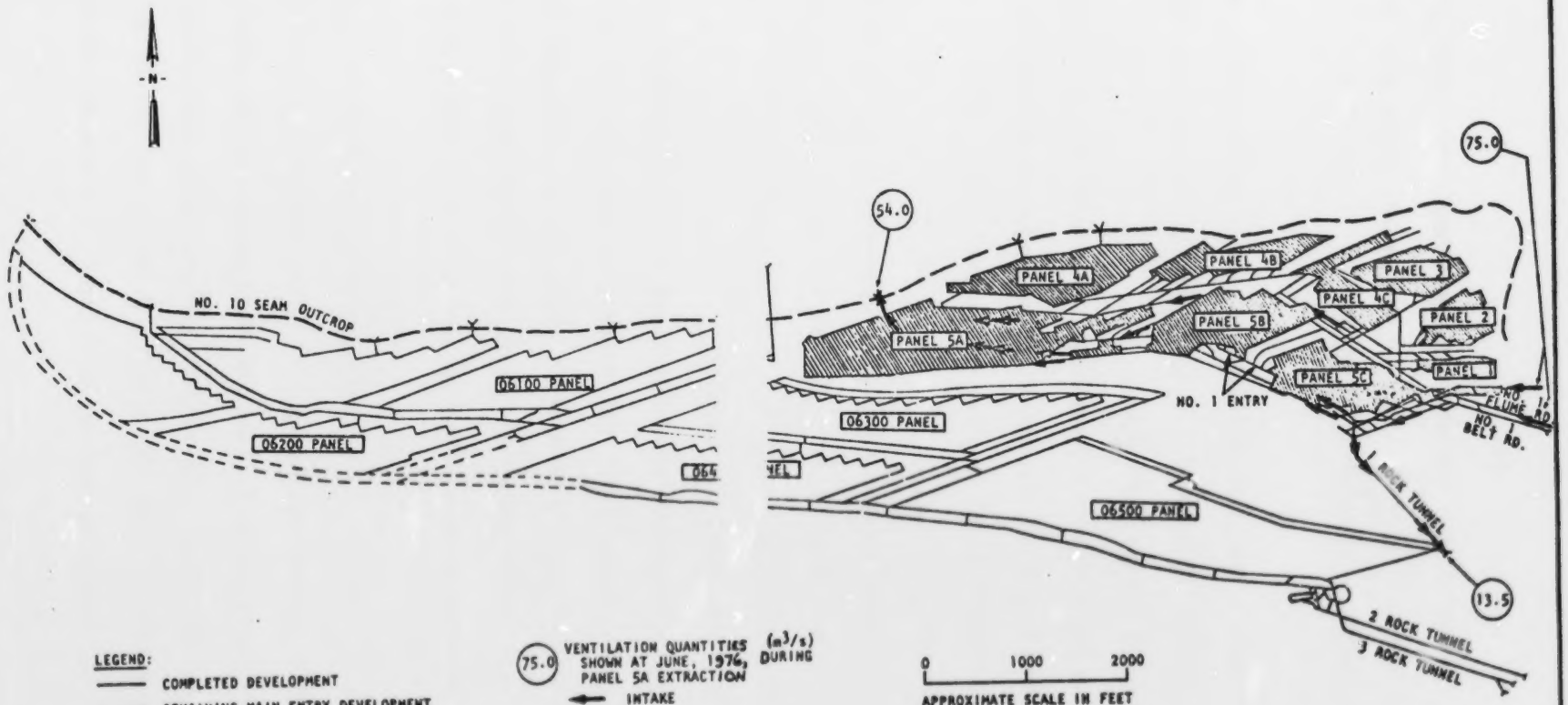

FIGURE 8

BALMER SOUTH MINE
NO. 10 SEAM MINING LAYOUT

DAMES & MOORE

SOURCE: KAISER RESOURCES LIMITED, 1979.

a return and venting to the outcrop was employed during the extraction of panels 3 and 4.

As extraction of panels 5B and 5C progressed, a different system of ventilation was employed. The gob area of panel 5A was sealed off and although the gob of the panel under extraction was still ventilated, the levels on the high side of the panel were not utilized as returns while those on the low side were intakes (Figure 7). Only one surface-forcing fan circulating 45 m^3/s was employed. The ventilating pressure ranged from 500 to 700 N/m^2.

Summarizing the ventilation system, forcing fans have always been used and the waste of the panel under extraction has always been ventilated. Ventilation has generally been ascensional. When panels bordering on the outcrop have been under extraction, the adits have been used as returns. When deeper panels have been under extraction, the levels on the high side of the gob have been utilized as return airways.

6.1.1.4 Future Operations

The future of Balmer South lies in the area known as panel 6. Figure 7 shows the layout of this section which will mine coal at elevations below drainage. Access to this area is via No. 2 and 3 rock tunnels, driven from the surface to intersect No. 10 Seam on the low side of panel 6. No. 4 rock tunnel has been driven to facilitate development of the most distant panels. Development of fluming and companion roads required for startup of panel 6 is more than 50 percent complete.

At the time of the consultant's visit plans for ventilating panel 6 had not been finalized. The same alternatives could be considered as for previous panels.

6.1.1.5 Description of Heating Experiences

Five separate heatings have occurred in the Balmer South Mine between 1972 and 1979. In two cases, the heatings have been very close to, or

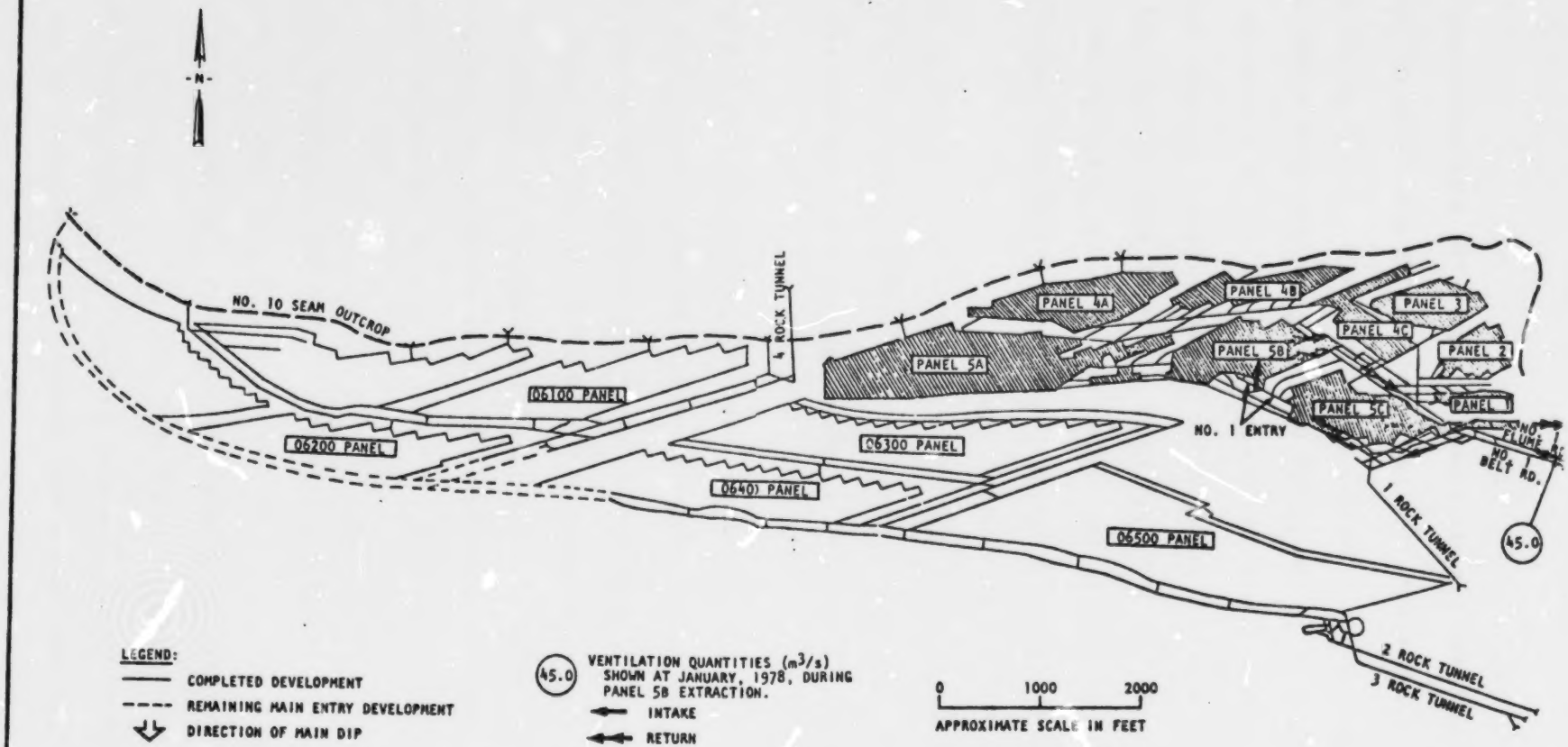

FIGURE 7

BALMER SOUTH MINE
NO. 10 SEAM MINING LAYOUT

SOURCE: KAISER RESOURCES LIMITED, 1979.

DAMES & MOORE

immediately at, the outcrop and were detected at the surface. In the other three cases, the heatings have been within panels which were either in the process of being extracted or had been completed.

The first heating which occurred in October 1972 was located at the outcrop of panel 2 one year after production from this panel had been completed. Very little barrier pillar was left and the strata caved right to the surface.

The second heating occurred in February 1974 in the gob of panel 4B. The heating was detected when smoke was seen to be coming from the fractured coal surrounding a wooden seal in the No. 3 sublevel. An attempt was made to dig out the fire using the hydraulic monitor but this was unsuccessful. Fourteen concrete seals were constructed in the sublevels and entries around panel 4B. It is though that this heating may have been initiated when ground movement, which occurred during the weekend, damaged the wooden seal mentioned previously.

The third heating occurred in April 1975, a short distance away from the site of the first fire in panel 2. This area was covered with a thick layer of crushed rock. The fire was still active in January 1978, but was confined to the outcrop (Chakravorty, 1978).

An automatic carbon monoxide monitoring system was installed in September 1976. No samples were taken of return air with the monitoring system since the gob of panel 5A, which was being mined at that time, was used as a return with air being vented at the outcrop. The four sampling points in the intake indicated an avearge CO content of 2 to 3 ppm with periodic highs of 4 to 10 ppm in the main flume roadway where diesel equipment was in operation. In October 1976, the heaters on the intake system were started for the winter and the background carbon monoxide content began to fluctuate over a wider range of 3 to 0 ppm with occasional highs

of 20 to 25 ppm (Chakravorty, 1978). This was the situation in January 1977 when the fourth heating occurred.

This heating was located in panel 5A and was first detected when spot samples taken in the return air at the outcrop showed a carbon monoxide value of 1000 ppm. At the time of the heating, the area was ventilated as described previously. There may be some significance in the fact that, shortly before the heating was noticed, a regulator in the upper intake was removed, changing the quantity of air ventilating the 5A gob. When the heating was detected the gob was immediately isolated by constructing seals and the ventilation was reorganised, as indicated previously with the levels on the high side of the panel being used as return airways. This reorganization allowed the installation of three carbon monoxide sampling points in the return airway during February 1977, leaving one sampling point in the intake.

The latest heating was detected on February 17, 1978 in panel 5B. The carbon monoxide monitoring unit had been operating during January but from February 1-14, the lines were frozen.

On February 14, the system was put into operation again and indicated a normal situation with 7 to 8 ppm in the main return on February 14-15. Then on February 16, the reading jumped to 18 ppm and on February 17 to 40 ppm. The upper limit of the apparatus was 50 ppm so, from February 18 to 21, spot samples were taken, and showed 90 to 160 ppm. The high carbon monoxide recorder was activated on February 22 and gave readings of 150 to 250 ppm for the rest of the month.

Meanwhile a mine inspection on February 17 had located a distinct haze and gob stink in the return airway. The part of the mine affected

was sealed off and inspected by rescue teams who were unable to locate the source of the smoke which had now appeared, except to say that it was not coming from the areas of panel 5B which were currently being extracted.

Arrangements were made to isolate panel 5B using seven steel reinforced concrete seals. The last seal was completed on April 29, 1978. By this time carbon monoxide readings had dropped to 80 ppm after reaching a peak of 400 to 500 ppm in early March. Eventually the reading was reduced to the normal range of 3 to 5 ppm.

It is thought that this heating may have been due to connections made between the gob of panel 5B and two old dip side drivages driven on the hanging wall.

6.1.1.6 Investigation of Susceptibility to Heating

As outlined, the Balmer South Mine has been affected by at least five heatings between 1972 and 1979. Loss of production and reserves has been significant. On two occasions after a heating has been detected in a panel the area has been abandoned, a coal barrier left inplace, and a new panel started. The loss of developed sublevels and the delay in developing replacements for them is expensive, but fortunately to date there have been no serious injuries.

Extensive tests have been carried out (Chakravorty, 1978) on the Balmer No. 10 Seam to assess the degree to which the coal itself is liable to spontaneous combustion. Proximate analysis of the coal shows it to be a low-medium volatile bituminous coal with a very low inherent moisture content and less than 0.5 percent sulphur. These qualities all indicate a coal which is not normally liable to spontaneous combustion. The coal is friable by international standards and this is one property which would encourage heatings.

However, a series of three tests were carried out (Chakravorty, 1978) to confirm these conclusions. The relative ignition temperature of No. 10

Seam, and a lignite known to be susceptible to heating, were examined. Heating curves were plotted for both coals and liability indices were found to be 4 for No. 10 Seam and 10 for the lignite.

The amount of oxygen absorbed by Balmer 10 Seam over a 96-hour period was measured at 30°C. The oxygen absorbed also indicated a low risk for the Balmer coal.

The presence of exinite in a coal seam is known to increase the liability of the seam to spontaneous combustion. Petrographic analysis of the seam indicated that exinite was not present.

These tests on coal properties lead to the conclusion that the heatings at Balmer South are not due to specific characteristics of the coal.

Many features of the Balmer South Mine environment do contribute significantly to the spontaneous combustion hazard. The thickness of the seam and the level of recovery achieved play a significant part. When operating at relatively shallow depths, fractures are created which extend to the surface, making it impossible to seal off the gob. It is possible that the level of recovery is high enough to cause fracturing, while low enough to leave significant quantities of coal behind to oxidize.

The sytem of undercutting the coal by hydraulic jet, and encouraging caving of the upper part of the seam, is significant. Whenever a gob collapses, causing the monitors to be moved back, much of the coal left behind is crushed and broken, increasing the exposed surface area and encouraging oxidation. This situation is common to any mining system which requires a thick seam to be undermined and is not limited to hydraulic mining.

The use of water to undercut and flush coal at the face may be a contributing factor, since heat produced during absorption of moisture by coal is known to encourage oxidization.

The use of continuous miners results in a high percentage of fines being produced as sublevels are driven. Spillage is likely to result in a concentration of fine coal along the line of these drivages.

While much of this fine coal is removed during hydraulic extraction of the pillar, some remains. The caving operation tends to add more fines. As broken coal flows down dip from the face to the feeder breaker in the sublevel, some settling takes place with the finer particles settling out on top of the debris which is left. The fines deposited towards the final stages of pillar extraction remain in the sublevel, and may increase the concentration of small coal at this location, contributing to the risk of heatings.

Since methane emission to date has been insignificant, large air quantities have not been required. Roadways of good cross section can be driven and maintained, and as a result the ventilating pressures required have been low.

The leakage of air necessary for heatings to develop occurs in spite of low ventilating pressures. Fractures caused by mining the very thick seam connect adjacent gobs to each other and the surface. They also prevent the efficient sealing of roadways, even when seals are built with great care.

If a liability index based on the mine environment is calculated (Feng, 1973) for most areas in Balmer South, it will be either 3 or 4 on a scale of 1 to 4.

There is little doubt therefore, that it is the mine environment, rather than the coal quality, which is the cause of the heating at Balmer South Mine.

6.1.1.7 Potential Future Fire Problems

As stated previously, no serious injuries have resulted from the

heatings which have occurred to date. The impact of lost production on the economics of the project has been lessened by the makeup of the operation. Only 20 percent of the total output originates from the underground mines, the remainder coming from a very large surface mining operation, in which substantial "in pit" reserves of coal are usually maintained.

In future operations in panel 6, significant changes will occur which may radically affect the problem of spontaneous combusion in Balmer South.

First, and most important, the methane emission rate is likely to increase. No methane has been detected in the return air from panels mined to date, in spite of ventilation quantities which have been relatively low compared to the tonnage of coal produced. This leads to the supposition that no significant quantities of methane have accumulated in the gobs, since emission rates have been low and the gobs of working panels have always been ventilated while those of worked out panels have been ventilated at least part of the time.

A further observation is that no instance of an explosion in a gob has been reported. This is particulary significant since the five heatings, all in areas which have been ventilated by small or even minute quantities of return air, would almost certainly have resulted in explosions within the gob, if methane had built up to a level in excess of 5 percent in the area affected by the heating. The state of the atmosphere within the gob can only be surmised since the evidence available is limited to measurements and analyses of return air. It should be appreciated that these analyses may not truly represent the atmosphere within the gob.

Thus, as the operations move to the deeper areas of panel 6, if higher methane emission rates are encountered, the danger of ignitions from any heatings which may develop, will be increased considerably.

The increased depth of cover will have an effect on two of the factors which cause heatings. First, the chances of cavities extending to the surface will be reduced, thereby lessening the danger of uncontrolled leakage of air from the mine through sealed areas.

Second, it is likely that the greater strata pressures will increase the quantity of crushed pillar coal inthe gobs, with a corresponding increase in the risk of heatings.

If methane emission rates increase, and as panel 6 involves the use of a more extensive ventilation circuit, larger ventilating pressures may be required, increasing the leakages around seals in the vicinity of the mined out areas.

In general, it is the consultant's opinion that the risk of heatings may be reduced slightly as depth of cover increases. However, the risk of an ignition of methane from a heating is likely to be significantly increased.

6.2 LONGWALL MINING

The only active longwall faces are operated by the Cape Breton Development Corporation (DEVCO) at the No. 26 and Lingan Mines in Nova Scotia. Although these operations are the main subjects of discussion here, reference is made to fire problems likely to be associated with planned longwall operations in western Canada.

6.2.1 DEVCO Mines

6.2.1.1 General Details

Both No. 26 and Lingan Mines use longwall advancing faces to extract reserves under the ocean from the Harbour Seam.

No. 26 Mine produces approximately 750,000 tonnes per year from three longwall faces and the associated developments, in an extracted seam thickness of 1.8 m to 2.0 m. Seam gradient ranges from 7.5 to 10 degrees. The

mine is extensively developed, and the furthermost face is approximately 9 km from the intake shaft at a depth of 700 m below the surface of the sea.

Lingan Mine produces approximately 1,700,000 tonnes per year from two longwall faces, limited room-and-pillar extractions and longwall development headings. The extracted seam thickness is 2.0 m to 2.13 m and the gradient averages 7.5 degrees. Lingan was developed in 1970 from three surface slopes of which two are intakes and one a return. The furthermost working face is approximately 5 km from the surface and the cover below the surface of the sea is about 400 m.

Outbye coal transport is by a combination of conveyor and trolley wire locomotive at No. 26 Mine and by conveyor at Lingan.

6.2.1.2 Longwall Operations

Advancing longwall face lengths range from 180 m to 210 m. Although the suppliers vary from face to face the equipment generally comprises double ended ranging drum shearers mounted on armoured face conveyors, to which either chock-type powered supports or, on the newer faces, shield-type powered supports are attached. The lower level intake brushing is broken down by selective roadheader while the return brushing is dealt with by drilling and blasting. Roadway support is by steel arches with wooden cribs mainly used along the sides. Faces are equipped and manned for intensive mining and continuous production. Weekly output for the most productive face averages more than 20,000 tonnes.

Mining difficulties are associated with the presence of stone lenses which are characteristically associated with the Harbour Seam. These consist of quartzitic sandstone intrusions, of indeterminate size and location, which periodically penetrate the coal. Dependent on location the seam roof is normally either shale or sandstone.

6.2.1.3 Ventilation Details

No. 26 Mine is ventilated through one intake shaft by a Sirocco radial flow forcing fan handling 162.5 m^3/s at a pressure of 2.65 kN/m^2. This fan is assisted by three inbye radial flow exhausting booster fans which handle 130 m^3/s at 2.35 kN/m^2, 67 m^3/s at 2.14 kN/m^2, and 37 m^3/s at 1.57 kN/m^2 respectively. Two return shafts each handle approximately 81 m^3/s and contain 1 ,ercent of methane. As these shafts are located approximately 2.74 km apart the total lengths of the respective ventilation circuits are 18.0 km and 20.4 km. For a distance of approximately 4.27 km, the approach to the Harbour Seam is through drivages in the Phalen Seam. These drivages provide multipath intake and return ventilation facilities; consequently most of the ventilation pressure is absorbed in roadways in the Harbour Seam.

Lingan Mine is ventilated by a radial flow exhausting fan handling 215 m^3/s at a pressure of 4.45 kN/m^2. The intake slopes handle approximately 104 m^3/s and 106 m^3/s respectively. The largest ventilation circuit is approximately 10 km and for a considerable distance ventilation facilities are provided in two intakes and three or four returns.

Methane emission rates, based on the methane content of the outbye return air, range from 25 to 40 m^3/tonne. Due to intensive face working this requires large air quantities to be circulated through the walls and airflow at the face varies from 15 to 20 m^3/s. Planned face advance is as much as 3,000 m and at present two faces have advanced more than 1,900 m. The extensive gob area, coupled with the rapid face advance, results in considerable gob air leakage such that quantities at the outbye end of the longwall roadways are as high as 40 m^3/s.

Methane control is assisted by the application of cross-measure borehole methane drainage techniques using roof holes in the return roadways.

Generally, 5 to 7 holes, spaced at 30 m intervals, are on line at any one time yielding 0.2 to 0.3 m^3/s of methane at a purity ranging from 35 to 65 percent. The capture rate for the drainage system is approximately 30 percent resulting in outbye general ventilation methane concentrations of about 2 percent.

The problem of excessive gob air leakage is being tackled in two ways. A proprietary foam is being sprayed along the intake roadside adjacent to the gob. This foam has little strength, and is more properly described as a "filler" rather than a "sealant;" it therefore is unable to resist damage resulting from strata movement. Reduction of pressure across the gob between the two face roadways, in order to minimise leakage flow, is achieved by ventilating through roadways of adjacent abandoned faces. This method of ventilation, referred to as the "cundy" system, entails the driving of a connection between the inbye end of the face return, through the 60 m rib pillar, to the old intake roadway of the adjacent face. This cundy connection then becomes the sole return and, while the former main intake retains that capacity, the former return outbye the cundy is converted to a low flow leakage intake. Control of flow in the leakage intake is maintained by regulators sited at its inbye and outbye ends. Careful and judicious adjustment of these regulators is exercised such that the airflow through each is the same. In this case a neutral point of ventilation is maintained between main and leakage intakes at some point approximately mid-way between the regulators. Outbye of the neutral point there is leakage flow through the gob from the leakage intake to the main intake, inbye of the neutral point the reverse takes place.

Typical airflows measured in the cundy ventilation system at Lingan Mine are 25 m^3/s in the main intake at the outbye end and at a point opposite the

intersection of the cundy with the return, 22 m^3/s entering the wall of which 10 m^3/s remains on the face and 12 m^3/s is near-face gob leakage, and 7 m^3/s at the inbye and outbye ends of the leakage intake. A flow of 32 m^3/s leaves the district through the cundy.

The advantages of cundy ventilation are:

1. pressure balance achieved across the major portion of the gob restricting air loss to that part of the gob between the faceline and the cundy
2. increased airflow available at intake brushing (up to 90 percent improvement on conventional method), increased face air velocity, improved methane dilution, reduced risk of methane ignition, methane fringe in gob pushed further away from face
3. material road in fresh air to the cundy

The disadvantages of this method of ventilation are:

1. use of abandoned roadways and old faceline for return ventilation and these may be in bad condition
2. delicate balance requires alert control of regulator apertures or methane problems may occur at inbye regulator, alternatively methane may flow into the main intake
3. passage of material cars through the inbye regulator badly affects balance if any door comprising the regulator is left open for any length of time
4. in the event that sealing off should be necessary to control an incident an additional two seals, at least, will be required
5. rapidly falling barometric pressure may result in the issue of methane at hazardous locations

6.2.1.4 Fire Precautions and Control

DEVCO's fire prevention and protection policies are detailed in a document, the aim of which is to set standards for fire prevention and protection in the interest of life, safety and property protection. The policy requires the provision of fire prevention plans, fire escape plans,

fire investigatory procedures, fire alarm systems, prefire training, and fire protection plans.

The mine fire prevention and protection plans comprise two parts. Part A describes the responsibilities of personnel on duty at the mine at the time the fire alarm is sounded. It also contains a prefire plan which shows the location of firefighting equipment. Part B describes details of the fire-fighting equipment to be provided as follows:

1. water supply from the surface through mains of such a diameter to ensure a rate of flow of not less than 2.84 l/s at the far end of the range (a 1.137 Ml static reservoir supply is available at the surface of Lingan Mine; No. 26 Mine obtains its water direct from the local public supply)

2. fire hydrants on the intake side at not more than 18.29 m from all conveyor loading and transfer points, main junctions, hoist houses, fan houses and substations; fire hydrants in close proximity to each longwall working face and elsewhere along fire ranges at distances not exceeding 152 m

3. 76 m of 38 mm firehose equipped with quick turn couplings and 38 mm fog nozzle in close proximity to each hydrant

4. a fire equipment tray on the intake side of the face equipment monorail containing, 244 m of 38 mm hose equipped with quick turn couplings packed in two equal skids, two 38 mm fog nozzles, one 38 mm fire curtain and two 6.8 kg ABC dry chemical fire extinguishers

5. on the material level, 15 m from the wall face, a water curtain preconnected to the 51 mm waterline

6. a map showing hydrant and firefighting equipment locations

In addition to the equipment which is mandatorily supplied in compliance with DEVCO requirements, conveyor belt drivehead protection devices are in use at Lingan Mine. All conveyor transfer points are manned and crews are organised to systematically clean belt structure. No automatic fire detection devices are in use and conveyor driveheads are not provided with sprinkler systems.

Inspection of firefighting appliances is systematically carried out at each mine by two safety officers. Written records of visual inspections are maintained although there is no systematic and regular measurement of water pressures and flows at hydrants. A 4-hour course of instruction on fire prevention and protection is given to new and other selected employees. During 1978 65 persons at No. 26 Mine received this course; 161 underground employees received a 1 hour lecture and demonstration on the use of fire extinguishers.

6.2.1.5 General Fire Experiences

Information supplied by the Canada Department of Labour shows that, during 1978 and the first 8 months of 1979, 23 incidents involving fire, overheating or flashing occurred at the No. 26 and Lingan Mines. The causes of the incidents were:

Friction on conveyors	5
Frictional sparks at cutting machines	7
Electrical apparatus	8
Ventilation and transportation equipment	2
Blasting	1

Thirteen incidents occurred at Lingan Mine, 10 at No. 26. In the majority of cases the situation was quickly brought under control by the application of water, rock dust or fire extinguishers. In some cases the flash was only momentary and in others the flame was self-extingishing due to lack of fuel.

During the stated time period there was no report of any gob fire attributable to spontaneous combustion associated with longwall mining. Incident records prior to 1978 have not been perused as part of this study. However, the only occasion brought to the consultants attention in which spontaneous combustion played any part in gob fire occurrence was at Prince Mine, September 1976, but this was not associated with longwall mining.

6.2.1.6 Major Fire Experience

Two major incidents have occurred in DEVCO's longwall operations in recent years. These are the fires which occurred on No. 11 South Wall, No. 26 Mine, on June 19, 1975, and the explosion which occurred on No. 12 South Wall, No. 26 Mine, on February 24, 1979.

LeBlanc (1976) describes details of the fire which occurred on No. 11 South Wall, an advancing face 183 m long in the Harbour Seam. The wall was inclined at 10 degrees and the coal contained stone intrusions consisting of a hard sandy shale or sandstone. The double-ended ranging drum drum shearer was fitted with pick face flashing and external water sprays for dust suppression and to extinguish frictional sparks. The seam was classified as gassy and approximately 19 m^3/s of air ventilated the face. In addition cross-measure borehole methane drainage was used to capture approximately 0.24 m^3/s of methane at 50 percent purity.

The fire originated from a methane ignition at the shearer when the machine was about 27 m from the top of the wall. After ignition a "ball of fire" was observed to travel up the wall and continued burning in the vicinity of the brushing of the return roadway. Burning methane was accompanied by crackling and rumbling noises in the roof in this area. It was decided to fight the fire which, by this time, was burning at a point 9 m outbye the brushing. In proceeding to the site through the wall senior personnel noted that the upper drum of the shearer was embedded into the roof stone. Firefighting using water, rock dust and carbon dioxide fire extinguishers continued for about 5 hours. Although considerable success was achieved initially, progress was halted by roof falls which dislodged the standpipe in a drainage hole allowing the methane issue to be ignited. Meanwhile conditions on the return side were extremely difficult with dense

smoke and considerable heat and condensation. It was therefore decided to seal off the fire with seals on No. 11 South coal roadway and in the main return deep at No. 9 South old coal roadway. These seals, composed mainly of bagged sand and rock dust, were completed in 7 hours. Ventilating doors in connections between the main deeps at No. 10 South coal road and No. 11 South material roadway were reinforced with bagged rock dust. Immediately upon sealing all men were withdrawn from the mine for a period of 24 hours.

During the next 5 days the mine was periodically inspected. Action was taken as required to improve the effectiveness of seals by spraying with Mandoseal and a sandbag dyke was built on No. 11 coal road to hold back water which was being pumped into the area to form a water seal at the lower end of the wall. In order to accelerate control it was decided to pump carbon dioxide into the fire area through the water pipes. This activity continued for 9 days during which time rescue teams were able to enter No. 11 South return roadway and build a rock dust seal. This resulted in control being effected such that 4 weeks after the initial incident the mine resumed production.

Periodic air samples were taken from the sealed area in order to assess fire progress. Approximately 3 months after sealing it was considered that an inert atmosphere had been maintained for a sufficient length of time for re-entry to be effected. Exploratory investigations initially took place through the return seal and subsequently, after dewatering, through the intake seal. Inspections revealed that there had been a very intense fire particularly at the top end of the wall which was inaccessible. Although it was decided to abandon the wall, after recovery of reusable equipment, about 1 month after reopening abnormal heating was detected in the face return roadway. The heat originated from the floor and became more intense inbye.

It was subsequently concluded that during the sealing off period the fire had migrated to a rider seam which occurs in the floor a short distance below the Harbour Seam. This deep-seated fire was resuscitated following the reopening and necessitated immediate resealing. Permanent seal construction was commenced in the face roadways and simultaneous completion of both seals was accomplished some hours later. Each seal was later faced-up with Mando-seal to minimise air leakage and the surrounding strata grouted.

6.2.1.7 Ameliorative Fire Control Measures

Major attention has been focused on the fire and explosion hazards arising from methane ignition by frictional sparking at the wall face when cutting picks contact seam intrusions or roof and floor strata. It has been DEVCO's policy for some years to drill and blast stone intrusions in the coal if it was considered that they would interfere with normal coal cutting. This would enable the machine to "flit" through these areas. Maintenance of adequate and sufficient ventilation at the wall has always been a major priority although this has presented appreciable problems due to the considerable gob leakage which occurs.

As a result of the major incident which occurred in February 1979, the following additional remedial measures have been introduced:

1. the return face roadway is brushed straight up to the face in order to improve ventilation in this location
2. the return roadway arch supports are set alongside the solid coal so eliminating any fast end, which is difficult to ventilate and in which methane could accumulate
3. light and heavy Polish-type rock dust barriers are installed
4. the alleyway which is maintained between the intake roadway brushing and the wall face is systematically rock-dusted
5. the brattice seal alongside the gob side edge of the alleyway has been reintroduced

6. a foam sealant is being sprayed along the gob support exposed on the intake roadway

7. four shift coal production has been reduced to three to allow for increased equipment maintenance

8. more intense maintenance of the Seiger BMI methanometer installed at the top of each wall has been introduced

9. devices for probing methane drainage holes for cracks and gas purity are in use

10. two additional main connections between the Phalen and Harbour Seams are being driven to reduce mine ventilation resistance

11. more extensive use is to be made of the cundy system of ventilation

12. more detailed reports of wall conditions and circumstances have been introduced

6.2.2 Other Longwall Operations

No longwall faces are operating in Canada at present outside the DEVCO organisation. However, there is a fairly strong possibility that longwall faces will commence in the foothills and mountains as well as the plains of western Canada. The former are unlikely to present a serious problem of spontaneous heatings, since the coal is high rank, low moisture and low sulphur. The mine environment will not encourage heatings. Open fires are unlikely to be as serious a hazard as at the DEVCO operations since, judging by experience to date, the methane problem in these seams has been less severe than at Lingan and No. 26 Colliery.

Spontaneous combustion may, however, be a critical factor at longwall operations in the low rank coal of the Western Plains. The room and pillar systems employed previously have not encountered heatings. However, they have generally operated at low levels of recovery and shallow depths. Low ventilating pressures and quantities have been the rule. Longwall operations will achieve higher recoveries and the use of shearers will create

more dust, leading to much higher ventilating quantities and pressures. This in turn is likely to increase the risk of spontaneous combustion.

6.3 ROOM AND PILLAR MINING

Several room and pillar operations have been active in western and eastern Canada in recent years. Both Canmore Mines and Coleman Collieries have mined seams ranging in thickness from 2.5 m to 8 m inclined at gradients up to 30 degrees. Recoveries have ranged from 30 percent to 70 percent of the coal in-place. These coals were semi-anthracite or low-medium volatile metallurgical. Canmore Mines have never experienced any problems with spontaneous combustion. Coleman Collieries did have one heating about 15-16 years ago, near the outcrop of the Vicary Creek Seam. This was extinguished very rapidly using water.

Both mines have had ignitions of methane at the coal face. The Vicary Mine has been fairly gassy and a continuous miner ignited a methane pocket when the picks struck rock at the face. The flame travelled back to a feeder in the floor but was rapidly extinguished by the men on duty.

At Canmore, two ignitions have occurred. One was in the Wilson Seam when the picks of a continuous miner struck rock at the face. Methane was ignited and feeders of gas issuing from the coal burned for some time before they were extinguished. In the second incident, methane feeders in the Stewart Seam were ignited when lightning struck either a pipeline or steel rail close to the mouth of the incline. These are the only recorded incidents at Canmore or Coleman. Both these underground operations closed down recently.

Kaiser Resources Balmer North Mine is extracting the Balmer No. 10 Seam using continuous miners and shuttle cars. Recovery is limited by the very thick seam and the capability of the equipment. The mine is ventilated

by an exhausting fan handling 92 m^3/s at a pressure of 1.5 KN/m^2. No problems have been encountered at this mine with heatings or open fires.

The McIntyre Mines operations are located near Grande Cache in northern Alberta. Apart from a brief attempt to longwall in the early years, the underground operations have been entirely room and pillar. Three seams have been mined at several locations. There has been no instance of spontaneous combustion at any time, though one abnormal carbon monoxide reading was recorded in the No. 5 Mine in the 4 Seam. It is surmised that this may have been due to a mistake in analysis or a flushing of a caved gob, since there has been no other carbon monoxide reading above the norm.

During 1976 a spontaneous heating occurred at the Prince Mine which is operated by DEVCO in Nova Scotia. The incident was controlled by digging out from the surface.

7. CONCLUSIONS

7.1 HYDRAULIC MINING

The Balmer South hydraulic operation is located at Sparwood, British Columbia. The Balmer 10 Seam is 15 m thick and steeply pitching with an average gradient of 30 degrees. The coal is a low-medium volatile bituminous with low moisture and sulphur. Extensive tests on this coal have shown that the heatings which occur at Balmer South Mine are not due to specific characteristics of the seam.

Five separate heatings have occurred between 1972 and 1979. Two of these were located very close to the outcrop. The other three were in panels some distance from the outcrop. The heatings have been expensive in terms of the loss of reserves and lost production.

The mine environment is considered responsible for the heatings at Balmer South. The thickness of the seam and the steep pitch combine to create a situation in which heatings are difficult to prevent. Recovery, though much higher than for a conventional operation, is limited by the geological parameters. The coal is friable and pillars crush easily. Due to the seam thickness, caving of the gob causes severe fractures which extend to the surface in all but the deepest parts of the mine. In addition, roadways close to the caves are severely fractured. Sealing of the gobs to prevent the admission of oxygen becomes very difficult.

Fortunately, no serious injuries have occurred as a result of the heatings experienced to date. The panels mined so far have produced insignificant quantities of methane and no ignitions have been detected.

As deeper panels are mined, methane emissions will almost certainly increase, leading to a very real danger of ignitions if heatings continue to be experienced.

7.2 LONGWALL MINING

Although longwall mining has been used in former years in western Canada it is only currently in use in Nova Scotia. To the best of our knowledge all Canadian experience is with advancing techniques in which there has been no recorded instance of a gob fire. Nevertheless any proposals for the extraction of western coal by these methods should recognise the potential gob fire hazards associated with low rank coals. These hazards may be exacerbated on high-production, intensively mined longwall faces with their increased ventilation requirements.

Open fires associated with existing longwall operations have mainly been due to frictional sparks, electrical short-circuits or blasting igniting a methane-air mixture, or frictional heat generated by some part of a belt conveyor igniting coal dust. Undoubtedly the major hazard has arisen from the rotating picks on power loaders cutting into roof or floor strata, or seam intrusions, creating an incendive spark which ignited methane.

High rates of longwall face production result in the emission of large volumes of methane even though the emission rate per unit of production may not be abnormally high. In Nova Scotia dilution of this gas has required large air volumes to be circulated in the mine. High air velocities result from large flow rates and as a result, in modern mining, large volumes of explosive methane-air mixtures are not expected in ventilated parts of the mine. The danger associated with local accumulations of explosive mixture is however very important. Although these accumulations are small they can be the fuse to a coal dust ignition. On the other hand, in those places in the mines in which ventilation is either nonexistent or uncontrolled there is a danger of a large gas body building up. A specific example of this is in the longwall gob. The hazardous conditions which can result from ignitions

at the face, leading to explosions or hanging flames which are most difficult to control, has been the major problem in Nova Scotia. Face ignitions by frictional sparks or blasting are therefore a more serious hazard than the electrically caused ignition which generally occurs outbye the face.

The heating of coal dust by friction generated at some point on a conveyor belt is a reoccurring problem. Fortunately, in antitropally ventilated mines these incidents are normally quickly detected and, as methane is not a problem, soon brought under control. Nevertheless the very serious consequences which can result from an unobserved conflagration originating in this way has been demonstrated in many other mines.

7.3 ROOM AND PILLAR

The room and pillar operations which are active in Canada at present are limited to:

1. The Prince Mine, Nova Scotia
2. The Balmer North Mine, British Columbia
3. The Sukunka Mine, British Columbia
4. The McIntyre Mines, Alberta

None of these operations have heating or fire control problems which compare with those at Balmer South, Lingan, or No. 26 Colliery.

8. RECOMMENDATIONS

8.1 HYDRAULIC MINING

8.1.1 General

In the body of the report the consultants have shown that the spontaneous combustion problem at the Balmer South Mine is extremely difficult to solve because of the seam thickness, the impossibility of completely sealing either underground roadways or fractures extending to the surface, and the absence of any real knowledge of the atmospheric conditions within the gob. The consultants have expressed the view that, while the frequency of heatings may lessen as coal is mined at greater depths, there will be a greater risk that a heating will initiate an explosion, since methane emission rates are likely to increase.

The best method of ventilating, and where necessary sealing off areas of the mine, is extremely difficult to determine, because of the absence of information on the state of the atmosphere in the gob. The extraction of 15-m-thick seams on steep gradients is very uncommon and experience from other operations is, therefore, limited.

These arguments lead to the conclusion that an effort to deal with the spontaneous combustion problem at Balmer South must have three main objectives:

1. To prevent heatings, or
2. To allow very early detection of those that develop, and
3. To ensure that, if heatings develop in locations close to the operating areas of the mine, methane-air mixtures will not be driven on to the fire

While (1) is obviously the prime objective, it would be foolhardy to assume heatings can be eliminated and to ignore the necessity for (2) and (3).

The consultants do not feel that they are able to make specific suggestions on radical changes in the mining or ventilation system. A few days spent at the mine, and the limited time allotted to this project, are unlikely to provide all-embracing solutions to problems which have existed for several years.

The seven recommendations which follow fall into three categories. The first three are intended to provide information which will lead to better understanding of the heating problem. This information should then permit decisions, on such controversial questions as whether or not to ventilate the gob, etc., to be made on the basis of fact, rather than conjecture. Two recommendations involve practical steps to be taken as part of regular mining procedures and may reduce the risk of spontaneous combustion. The final two recommendations outline investigatory procedures.

8.1.2 Additional Gas Sampling

The present monitoring system has the facility to sample from four separate points. Usually one sampling point is in the intake and three are in the return. As the faces retreat, the sampling points are moved outbye. No samples are taken from the gob.

The consultants suggest that the present system should be expanded to cover at least eight sampling points. Of these, four should be located in the gob. This is probably a minimum number and should be increased if at all possible. By locating a sampling point in every second or third sublevel, and alternating locations between the high side and the low side of the gob, a fairly uniform distribution of sampling points would be obtained.

Obviously, the plastic pipe used at present will be useless to draw samples from areas which will cave. Use of small steel pipe, 10 to 15 mm diameter, is suggested. This could be laid on the floor of the sublevels

to be sampled and would be protected from damage by the cushion of debris below and a small amount of debris placed on the pipe. Protecting the sampling points would be more difficult. A small steel box, perhaps 200 to 300 mm square, could house the rough filter which would be located near the top of the box. The box would be protected by timber before the waste caved. If short lengths of steel pipe were connected to vent holes in the side of the box, this would ensure that the atmosphere within the gob could be sampled, since all the pipes are unlikely to be blocked. All connections would have to be sealed to prevent water entering the sampling pipe.

The sampling points located in the gob would serve two important functions:

1. If a heating occurs, these sampling points may be closer to the source of the carbon monoxide and might provide an earlier warning of an abnormal analysis than the present sampling points in the return airway

2. By analysis of the samples taken from a number of points in the gob, the percentage of methane, carbon monoxide, carbon dioxide and oxygen can be determined. This will provide information on such controversial and critical questions as whether methane builds up in the gob and, if it does, how rapidly does it reach the lower explosive limit

   By having sampling points on the high side of the gob any methane accumulation at that level will be detected even though the sampling point is at floor level. If the gob is ventilated, the analyses will show whether the general body is clear of methane, or only that portion which offers a preferred path for air. If an ignition occurs well back in the gob, this may be recognized by the effect on samples. If an inert atmosphere builds up in the gob, this will be detected. Most important, the scattered sampling points may provide information which allows the location of any future heating to be determined

8.1.3 Modelling of Ventilation Patterns in the Gob

It may be possible, by means of physical or numerical modelling, to estimate the effect on the atmosphere in a semi-consolidated or

open gob when different ventilation systems are employed. If this was done, much of the uncertainty might be removed from the discussions concerning the advantages and disadvantages of ventilating the gob. The effect of various methane emission rates and of rearranging ventilation seals and regulators, could be simulated. Numerical modelling has been used extensively in ventilation planning so the techniques are proven for orthodox circuits. Whether they can be applied to gob areas effectively, requires investigation. This type of modelling may be particularly informative if data from the gob sampling system is utilized in the model.

8.1.4 Recording of Incidents

The consultants suggest that an experienced mining engineer should be given the responsibility of preparing a brief written record of the events leading up to each heating which has occurred and of the steps taken to deal with the incident. Even more important, if another heating does occur, the same engineer should be responsible for preparing a detailed record of the circumstances existing before, during, and after the event.

8.1.5 Timber as an Agent of Spontaneous Combustion

The role played by timber in the heatings at Balmer South is uncertain. On at least one occasion, lagging boards surrounding the arches have been observed to be burning. Whether this was a result of the heating, or a contributory factor, is not known.

Timber has been known to play a major role in heatings. At first glance the likelihood of timber being a critical factor in the Balmer South heatings does not appear very high. The small amount of timber involved relative to the quantity of coal remaining tends to encourage this view. On further reflection, however, it is quite possible that timber is a factor. Arguments in favour of this are:

1. The coal itself does not have qualities which render it likely to oxidize rapidly and the tendency is to blame the mining environment. Timber, on the other hand, does have the qualities necessary to support spontaneous combustion and may encourage heatings

2. The quantity of timber is small, but it is concentrated entirely along the sublevels and most of the lagging boards are left behind. These sublevels are not only a preferred path for any air leakage, even when the gob is partially consolidated, but they also contain accumulations of fine damp coal which have settled out during the hydraulic mining operation. The type of coal, in fact, which is most likely to oxidize

3. The sublevels are open much longer than the gob and may approach more rapidly the incubation period of the coal

If timber is a hazard, it would be preferable to replace it by corrugated steel sheets, or weldmesh. However, since this is clearly difficult to arrange, timber which has been impregnated with fire-proofing chemicals to prevent oxidization and decay, could be used. This would be a very simple and practical step which might play a significant part in eliminating heatings.

8.1.6 Sealing of Fractures on Roadways

If the fractures which occur on roadways where panel seals have been constructed could be sealed, this would be an important step forward in sealing gobs. The effort would be particularly worth while when the gobs are at depth, beyond the range at which fractures extend to the surface. However, introduction of an experimental program to apply various forms of sealant to stoppings, and the roadway perimeters nearby, is a major undertaking compared to the other programs which have been recommended. For this reason, the consultants suggest that the simpler recommendations for gob sampling, timber treatment, modelling, etc., should be initiated first with a sealing program to follow. This should not be construed as a comment on the importance of sealing. Rather, the recommendation takes into

account the chances of success for such a program and the very considerable effort involved.

8.1.7 Adjustment of Humidity Underground

During discussions with the staff of Kaiser Resources, the influence of humidity on spontaneous combustion was considered. It is well known that changes in the moisture content of fine coal can cause both heating and cooling. The drying effect of the ventilation current in winter, when humidity is very low, may be a factor in causing spontaneous combustion. This has been suggested as a possible reason why the three fires in gobs away from the outcrop have occurred in January or February.

The consultants suggest that this question should be investigated by Canmet and, if the investigation indicates that humidity may be a critical factor, a system for increasing the humidity of the intake air during the winter could be initiated.

8.1.8 Construction of Seals

During a visit to the Somerset Mine in Colorado, the consultant was shown seals which had been constructed around an active fire area. The seals were unusual in that a mixture of cement, fly ash, bentonite and water was pumped into the space between the bulkheads. A letter is enclosed in the Appendix which describes the procedure.

Two bulkheads are erected, the distance between being decided by the strength of seal required. The bulkheads are heavily braced and set well into the roof, floor, and sides of the roadway. Several holes are drilled into the channel cut in the roof from the roadway. Steel pipes are grouted in these holes. The mixture is then pumped into one pipe until material runs from the others.

Experience has shown that the grout material penetrates the fissures surrounding the roadway, resulting in a particularly effective seal even when the strata is badly fractured.

At the Somerset Mine, management indicated that pressure and heat were generated during the curing of the grout, resulting in more effective grouting than that produced by normal pumping pressures.

The consultants suggest that if further seals are constructed at Balmer South, this method of construction should be considered.

8.2 LONGWALL MINING

The following recommendations are primarily aimed at identifying measures to assist in the prevention and control of fire hazards which have previously presented problems in Canadian longwall operations. Three main technical areas are of interest, as follows:

1. sources of ignition
2. combustible fuels
3. fire control measures

8.2.1 Sources of Ignition

Four major igniting sources may be identified - frictional sparks, frictional heat, blasting and electrical equipment.

The occurrence of incendive sparks when high-speed cutting tools contact certain types of hard abrasive stratum is inevitable. The types and properties of stratum providing the greatest frictional spark hazard have been researched in a number of countries for many years and the results are well published. The type, shape, construction, number and application of picks to reduce the hazard has likewise been investigated. The application of water to suppress sparks has been the main practical measure applied.

Heat generated by frictional contact with moving parts of belt conveyors has, and always will be, a mining problem in those places where coal dust is allowed to accumulate. Prevention lies in competent and systematic inspection and mechanical maintenance, with organised belt patrol and clean-up crews.

The hazards associated with blasting have been thoroughly researched over many years and the conditions under which certain types of explosive may or may not be used are well known. Further improvements in safety are more likely to result from the application of increased personal responsibility by all personnel who have duties related to blasting. The solution is more directly associated with education rather than technical improvement of equipment. In this case it is desirable to eliminate underground blasting completely and it is recommended that in all cases where it must be used investigations should be commenced to identify suitable alternatives.

Similarly, the hazards arising from the use of electricity are mainly associated with human errors. Proper design, construction, choice, installation, location, use, maintenance and inspection of electrical apparatus would result in the elimination of most electrical incidents. The provision of thoroughly trained, systematically organised and properly deployed electricians are fundamental requirements.

A consideration of the major igniting sources of fires in Canadian coal mines does not readily suggest suitable areas of technical research which should be immediately investigated in order to provide practical assistance to operators.

8.2.2 Combustible Fuels

The need to prevent and suppress coal dust and to avoid the occurrence of accumulations is well known. The extent to which admixture with rock dust

is necessary to reduce combustibility has been well researched. The opportunities for applied research associated with coal dust as a combustible fuel are therefore limited.

The chemical and physical combustion properties of methane-air mixtures are well understood. Flame propagation in flammable mixtures in a variety of laboratory models, simulating underground conditions, has been investigated and has helped to explain the reasons and circumstances involved in actual mine incidents. However the source of methane, its emission into the mine, and methods of controlling the gas are still subjects requiring further applied research.

An earlier report by Dames & Moore and H.G. Stephenson (Mining Consultant) Ltd. (1978) discussed the studies which should be initiated to identify methane sources. Research investigations should identify sources associated with the seam being mined and all other sources within the relaxed zone above and below the excavation. Having identified the sources, the magnitude of each should be assessed. This investigation would be based on a study of existing ventilation data and methane records and desorption tests on cores of the surrounding methane-emitting strata. Having located and assessed the methane sources the appropriate control techniques could be identified.

A detailed analysis of any existing ventilation system in which accumulations of flammable gas have occurred should be carried out. The circumstances surrounding the excessive leakage which occurs through the gob of advancing faces requires particular investigation. The need to maintain high ventilation pressures should be addressed. Layout redesign should be investigated to ascertain if problems can be designed out rather than implementing ameliorative measures. If preventive measures are to be implemented

research should be directed to the identification of sealants suitable for use underground. The appropriate sealant properties should be identified and tests devised to assess the efficiency of each. Where methane control techniques are already in use their efficiency should be investigated and trials initiated aimed at securing improved operational results.

8.2.3 Fire Control Measures

The fire incidents associated with Canadian longwall operations have mainly occurred as rapid ignitions in the presence of workmen. It has therefore been possible to quickly initiate firefighting procedures. The provision of automatic fire detectors would be of little value other than for the smouldering fires which have resulted from prolonged conveyor belt friction. The applicability of automatic detectors in Canadian mines should be investigated with specific regard to this type of incident. Under suitable circumstances smouldering fires can have disastrous results and to rely solely for their detection on observations of personnel is not wholly satisfactory.

In the event of an outbreak of fire or explosion the containment of the incident by water or rock dust barriers, strategically located, is very important. The applicability of barrier types best suited to Canadian condition should be investigated with a view to their widespread installation.

Extensive gob areas in longwall mines remain unsealed and open to ventilation. Selected areas should be chosen for investigation into the efficency of seals, the application of pressure chambers, the advantages of pressure balancing and the opportunities for methane drainage. Experience gained with pressure chambers in controlling methane emission from old workings would enable expertise to be developed in pressure balancing, which could be of considerable value in the event that emergency seals had to be

erected to control an incident. Due to the high ventilation pressures in use at DEVCO's mines the need to balance pressures on the face of completed seals is particularly important.

Technical advances in the construction of seals and in the materials used should be investigated to enable Canadian operators to take advantages of most recent developments. The speed with which explosion-proof seals may be erected is a vital factor in the control of an incident and certain proprietary materials may be very rapidly placed.

Reopening of sealed areas by either the air-lock or direct ventilation method is largely dependent on local mining conditions and practical experience. There does not appear to be any opportunity for an applied research activity in this connection associated with the sealed No. 11 South wall at No. 26 Colliery.

8.3 ROOM AND PILLAR MINING

No research work associated with room and pillar operations is recommended at this time.

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APPENDIX

MESA Letter Describing Construction of
Fly Ash/Bentonite/Cement Seals at
Somerset Mine, Colorado

United States Department of the Interior
MINING ENFORCEMENT AND SAFETY ADMINISTRATION
4800 FORBES AVENUE
PITTSBURGH, PENNSYLVANIA 15213

RECEIVED
MAY 2 1975
GEN'L SUPT.
WESTERN DIST.
COAL

April 28, 1975

Boyd McKeen
U.S. Steel
PO Box 807
East Carbon, Utah 84520

Dear Boyd:

Good talking to you Friday and good to hear that you plan to construct additional flyash-cement bulkheads. Your experiences with these in the Somerset Mine Have been important contributions to better mining. Would you or Paul Watson consider giving a paper on these, perhaps at the December meeting of the Coal Mine Institute or the Smokeaters.

Now to your questions. I believe you said the four bulkheads are to be constructed in openings that approximate 9-feet in height and 18-20-feet in width and are to withstand a 70-foot head of water. Using the dimensions 10 x 20 and the Genthe formula,

$$\text{Thickness } (T) = 0.865a\sqrt{\frac{Q}{S_f}} \quad \text{where}$$

a = the largest dimension,

Q = the static load to be withstood, and,

S_f = the flexural strength of the bulkhead material:

$$T = (0.865)(20)\sqrt{\frac{(70)(0.434)}{150}} \doteq 8'$$

The calculated thickness, 8 feet, has a number of inherent factors of safety:

1. Research here and in Germany indicates that bulkheads designed according to that formula withstand explosions developing loads 3 and more times greater than the Q used in the calculation.

2. Using the formula we have suggested for explosion-proof bulkheads, $T = \frac{1}{4} W$, the thickness needed to withstand an explosion would be 5 feet.

3. The S_f value of properly mixed flyash-cement after curing for 30 days probably will exceed 500 psi which, had that value been used, would result in T = 4 1/4'.

However, for safety's sake, recognizing the potential hazards from the tremendous body of water to be impounded please consider some of the following:

1. T = 10 feet.

2. Full-column resin bolts anchored at least 3 feet into the roof and floor and extending 2 or more feet into the bulkhead near its corners.

3. Sturdy bracing at the 1/3 and 2/3 heights of the form.

4. Grout the ribs around the opening in which the bulkhead is to be constructed to reduce their permeability and to improve their mechanical properties. For this, and relying solely on my memory of typical Somerset B-seam characteristics, I suggest holes be below and above the slate band. I would space the holes on 10-15 foot centers and drill them 8-10 feet deep. Using a good hole packer, pump the grout in until it begins to flow out of the nest hole--use as low a pressure as possible to prevent rib roll out or other damage. A first time grout formula could be:

Portland cement	1	part by weight
Flyash	5	parts by weight
Bentonite with wetting agent	0.2	part by weight
Water	2	parts by weight

Second, third, etc. formulas involve changing the water content--the least water is wanted. More water is suggested if the grout does not flow from the neighboring holes; less water if it flows from those holes before it shows on the rib.

The flyash should meet ASTM C618-71. The seller should prove that. In addition, the SO_3 and free lime contents should be not more than 1/2 and 1 percents respectively. Those were the ingredients, I believe,

mainly responsible for the high temperatures of hydration we encountered in 2 Raise bulkheads. If these percentages are greater then plan to use 3 ounces of Pozzolith 300 N (from United Ready Mix in Grand Forks) per sack of cement or use Type 4 rather than Type 2 cement.

Water--that is the key ingredient. You could use the same quantity as in the past. However, there is a simple test, called Bituminum Number Index, that in 1 minute determines the optimum water content. This is valuable because optimum water depends on the carbon content of the flyash which content may be quite different between deliveries from a plant as well as between plants. The test apparatus costs $400. I don't have it. Should you be interested you could ask for the National Ash penetrometer from Mr. Lindbolm, Humbdt Company, Chicago, 312-456-6300. The plunger, which is given at no cost, is obtained from John Faber, National Ash Association, Suite 650, 1819 H. Street, N.W., Washington, D.C. 20006 (202-659-2303).

Boyd, I hope this has helped. Please feel free to call if there are any other questions. And please give my regards to the Pauls (Watson and Clark).

Cordially,

Donald W. Mitchell
Mining Engineer
Technical Support

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